Modeling Study of Surface Energy Balance with Monin-Obukhov Similarity Theory Closure

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Outline

- Basic Idea
- Algorithm
- Results: modeling vs. observation
- Discussion

Basic Idea

- Surface Energy Balance Equation

$$R_{N0} - G_0 = H_0 + \lambda E_0$$

- Diagnostic form:
  - Heat capacity of ground—zero ; ground heat flux – zero;
  - the terms in SEB are either computed separately or parameterized in terms of Ts, so that the equation is solved iteratively
  - Non-rate equation for *Ts*

Basic Idea

- Through parameterization, SEB contains Ts as an only unknown variable
- Known variables: incoming Solar radiation, albedo, incoming longwave radiation, wind speed

Algorithm

- Net radiation – defined as:

$$R_N = S\downarrow - S\uparrow + L\downarrow - L\uparrow$$

- All the terms in the SEB are either specified from the dataset or parameterized in terms of *Ts:*

$$S_d(1-a) + L_d - \varepsilon\sigma T_s^{\ 4} - (1-\varepsilon)L_d = c_p\rho(T_s - T_a)/r_a - \lambda\rho(q^* - q)/(r_s + r_a)$$

Algorithm

- Given specified L_d, a, S_d, the resistance needs to be parameterized in terms of *Ts* so as to close the whole system
- Theoretically, one can solve the SEB for surface temperature *Ts*, since *Ts* is the only unknown variable in the system
- Nonlinear system, thus Newton's method applied

Algorithm – Monin-Obukhov Parameterization

- The resistance parameterization scheme should involve the surface temperature *Ts* as the only unknown variable
- Big-leaf model:
  - Aerodynamic resistance
  - Stoma resistance
- At this stage, only incorporate the subroutine of aerodynamic resistance by leaving the stoma resistance as a constant

Algorithm – Monin-Obukhov Parameterization

- Based on Monin-Obukhov similarity theory, different models proposed
- According to *Liu et al(2006),* Choudhury (1986), Thom(1975), Xie Xianqun(1988) model showed better agreement
- *Thom and Xie'* model applied in this study

Algorithm – Monin-Obukhov Parameterization

- *Thom model*

$$r_a = \frac{1}{k^2 U_z} * \left[\ln(\frac{z-d}{z_0}) - \Psi_m(\frac{z-d}{L}) \right] \left[\ln(\frac{z-d}{z_T}) - \Psi_h(\frac{z-d}{L}) \right]$$

In neutral condition, $\Psi_m = \Psi_h = 0$

In unstable condition, $\Psi_m = 2\ln(\frac{1+x}{2}) + \ln(\frac{1+x^2}{2}) - 2\arctan(x) + \pi/2$

In stable condition, $\Psi_m = \Psi_h = -5\xi$

where,

$$\xi = \frac{z-d}{L}$$

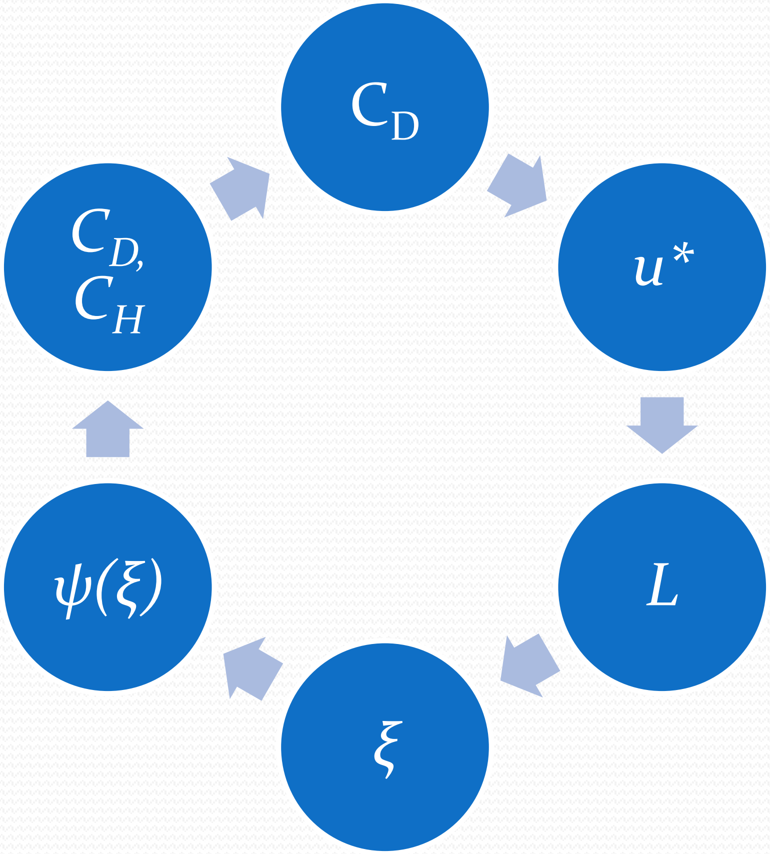
$$x = (1-16\xi)^{1/4}$$

Algorithm – *Thom model*

- How to evaluate L :
  - L is a funtion of $u*$ and Ts
  - $u*$ can be calculated from C_D
- Therefore, all the quantities are looped tegother:

Algorithm – *Thom model*

Loop:



Algorithm – *Thom model*

- Convergence problem:

  A good initial guess is required for convergence

- How to get a close guess for C_D
  - C_{DN} (neutral condition) is introduced to trigger the loop
  - C_{DN} is only dependent on $z\text{-}d$ and z_o

Algorithm – *Thom model*

- Convergence problem:
  still encounter unconvergence

- Examine the shape of drag coefficient

Algorithm – *Thom model*

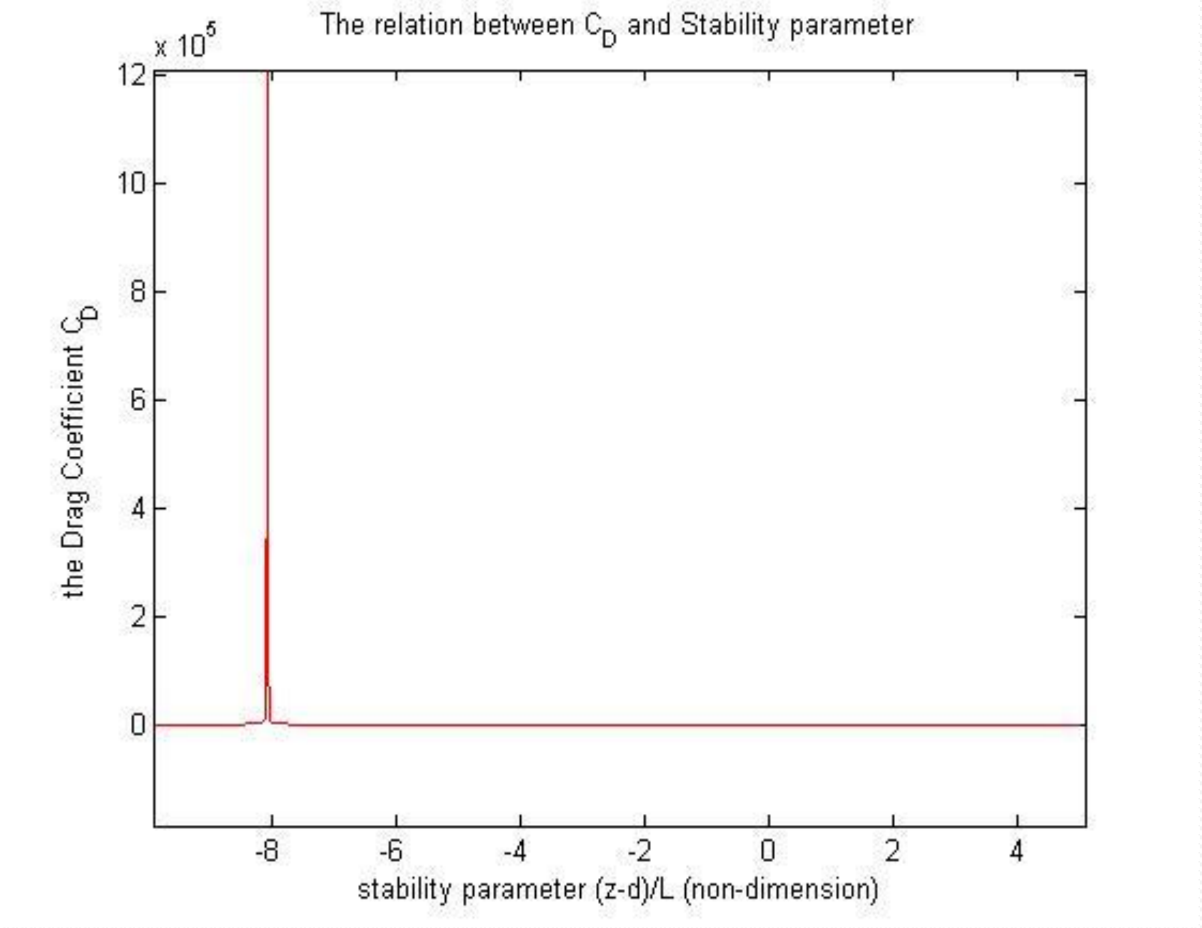
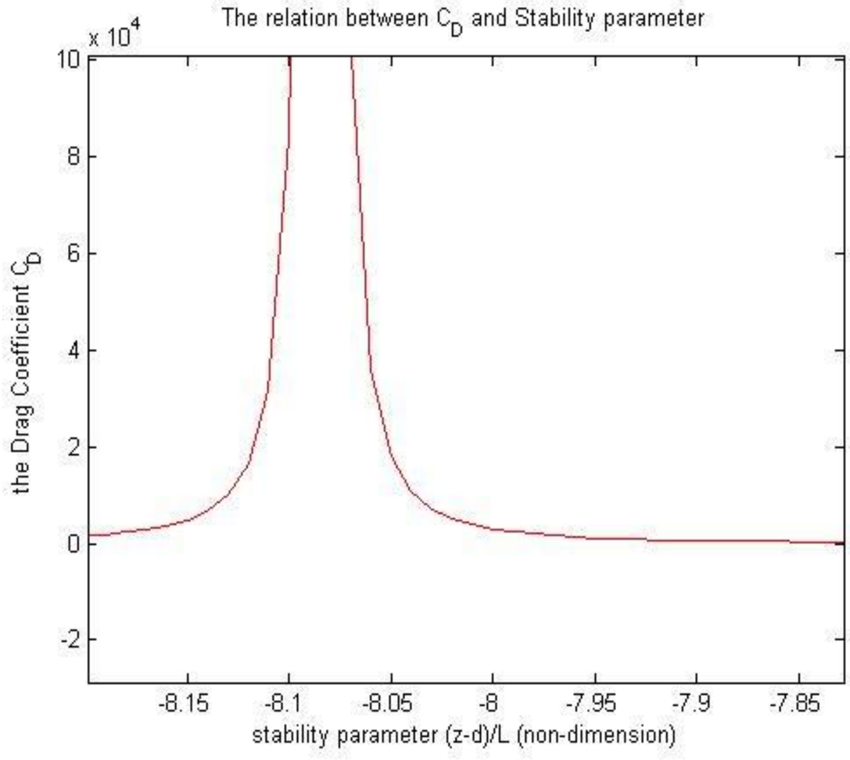


Figure 1 Relation of Drag coefficient C_D vs. Stability correction function ψ

Algorithm – *Thom model*

- Therefore, some thresholds for ξ are needed
- As widely used in the literatures, ξ is cut in the interval between -5 and 1



Algorithm – Monin-Obukhov Parameterization

- *Xie' model*

$$r_a = r_{aa}\left[1 + \frac{\Phi_h}{\ln(\frac{z-d}{z_0})}\right]$$

r_{aa} is the aerodynamic resistance in neutral condition, $r_{aa} = \frac{\left[\ln(\frac{z-d}{z_0})\right]\left[\ln(\frac{z-d}{z_T})\right]}{k^2 U_z}$

In neutral condition, $\Phi_h = 0$

In unstable condition, $\Phi_h = (1-16\xi)^{-1/2}$ $\xi < -0.03$

In stable condition, $\Phi_h = 1 + n\xi$ $\xi > 0$ $-0.03 < \xi < 0$

where, *n* is empirical coefficient, when $\xi > 0$, *n*=5.2; when $\xi < 0$, *n*=4.5

Algorithm – *Model structure*

- Newton's method is the main iteration for solving *Ts*
- In each iteration, new computed *Ts* goes to the resistance loop for resistance calculation
- The resistance return to the main iteration for calculating a newer *Ts*

Input data

- Driven by: the measurements of incoming solar radiation, surface albedo, incoming longwave radiation, and wind velocity at a certain height

- Data used: Old aspen site 2000 Jan.

Results

- Comparison between the modeling results and the observations:

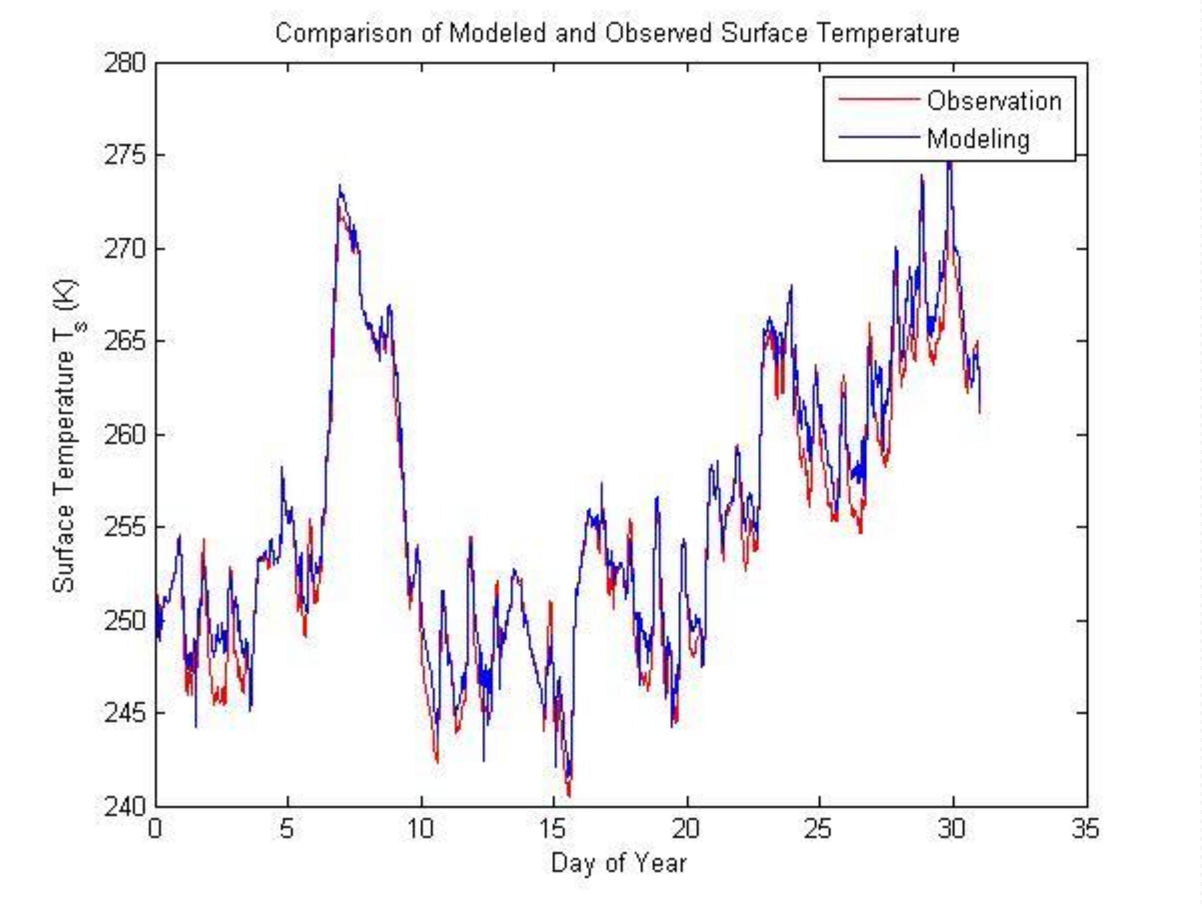
  Surface Temperature – Ts

  Sensible Heat Flux – H

  Latent Heat Flux – λE

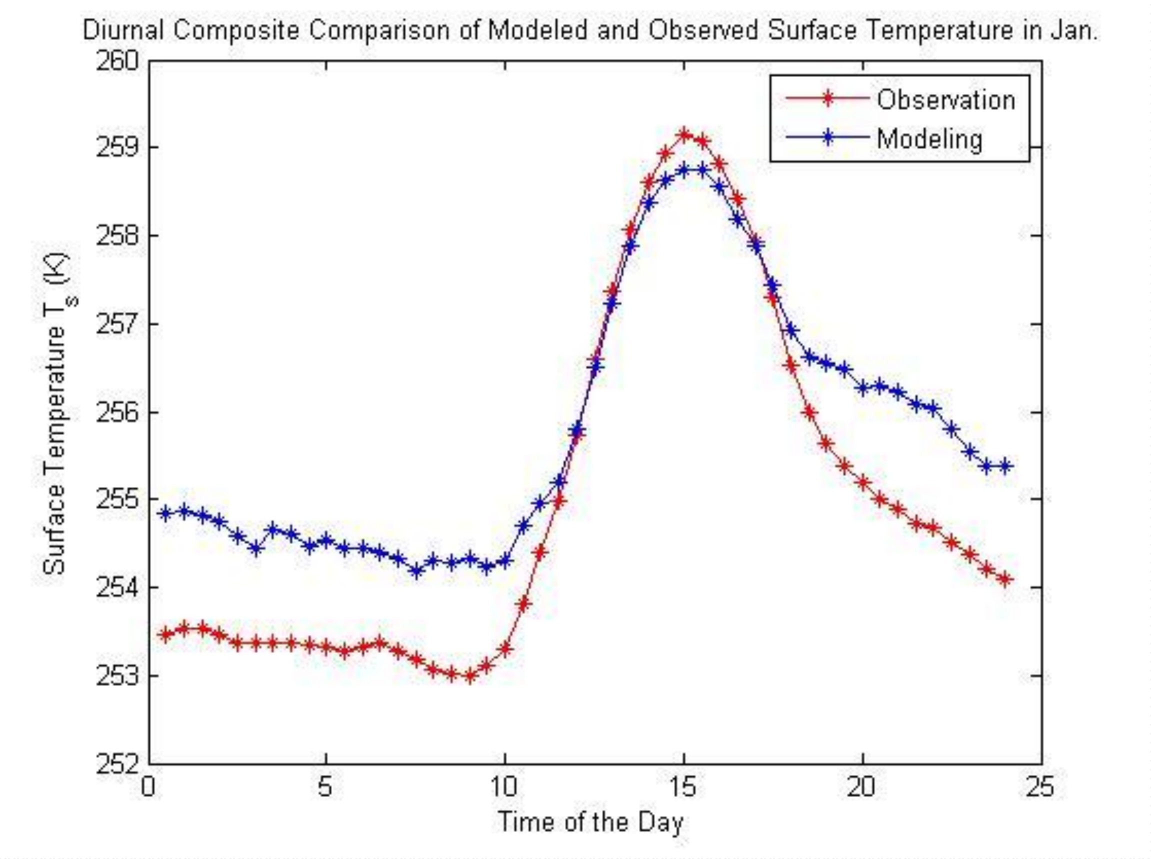
Results - Surface temperature

- Thom model



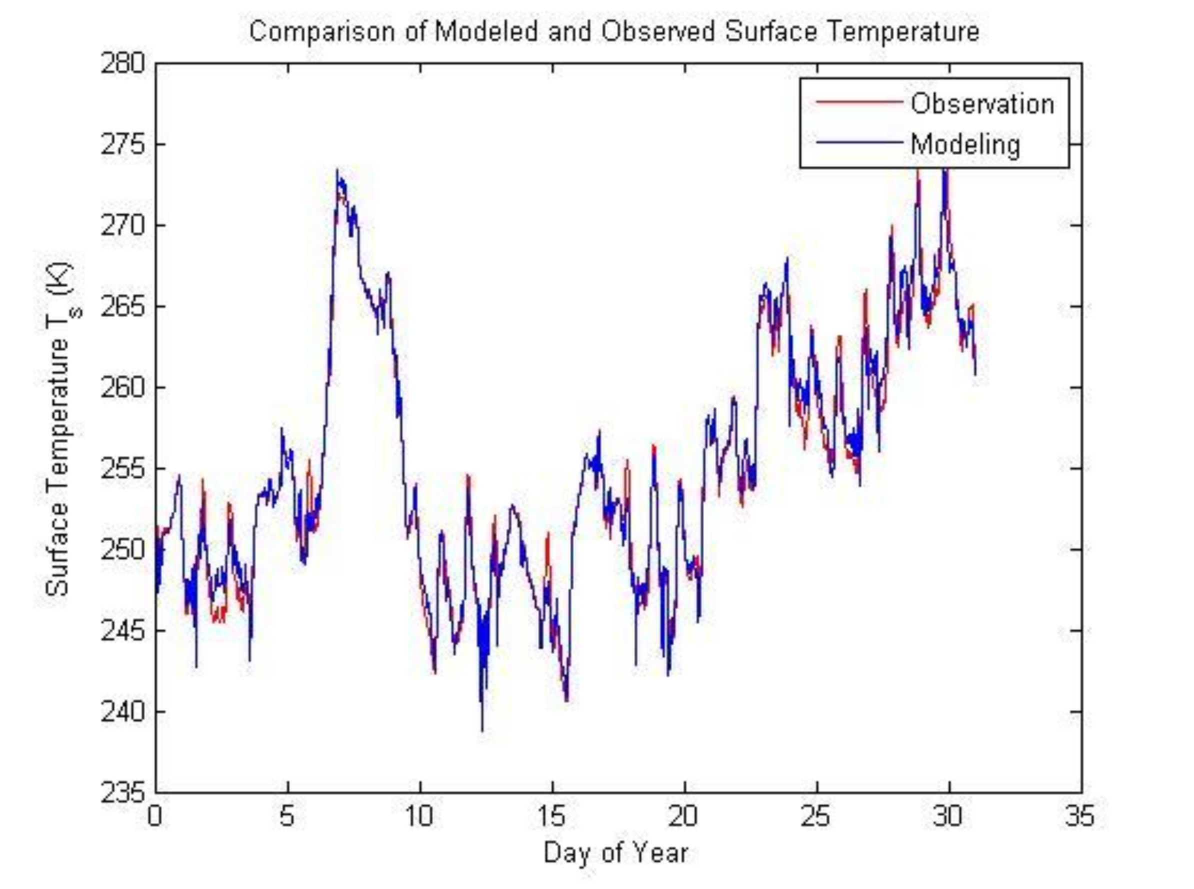
Results - Surface temperature

- Thom model



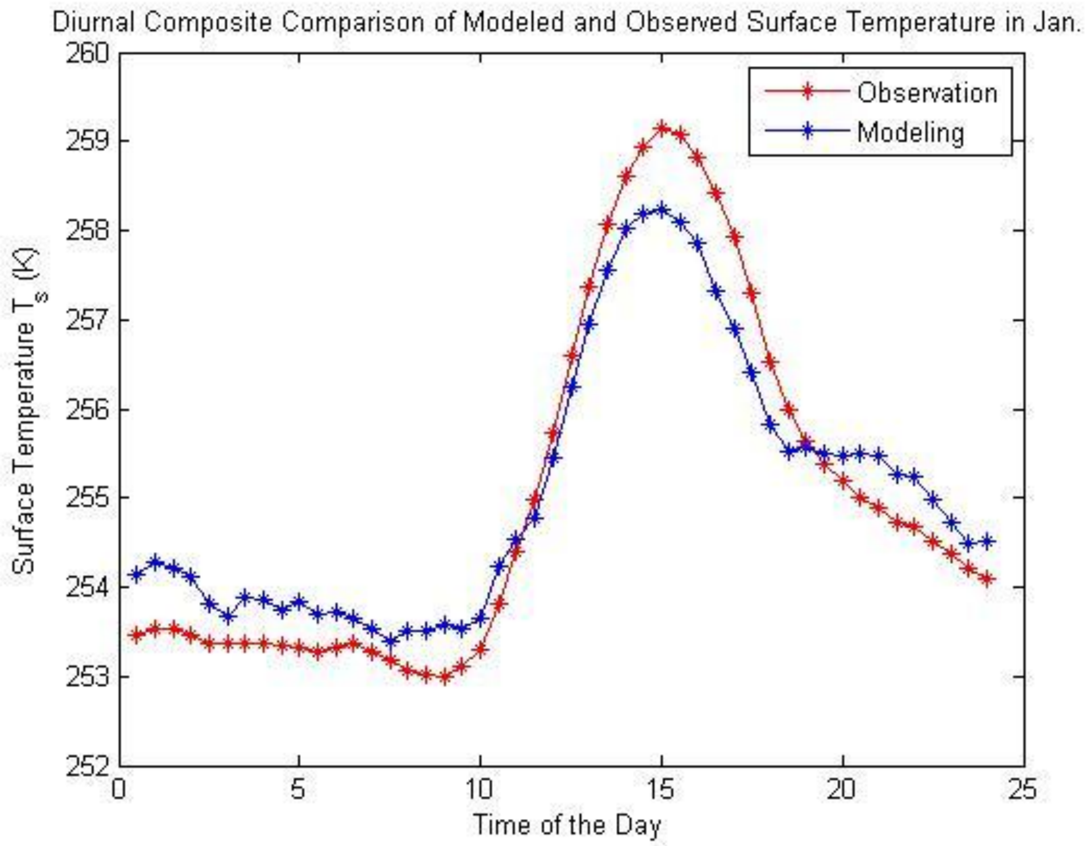
Results - Surface temperature

- Xie model



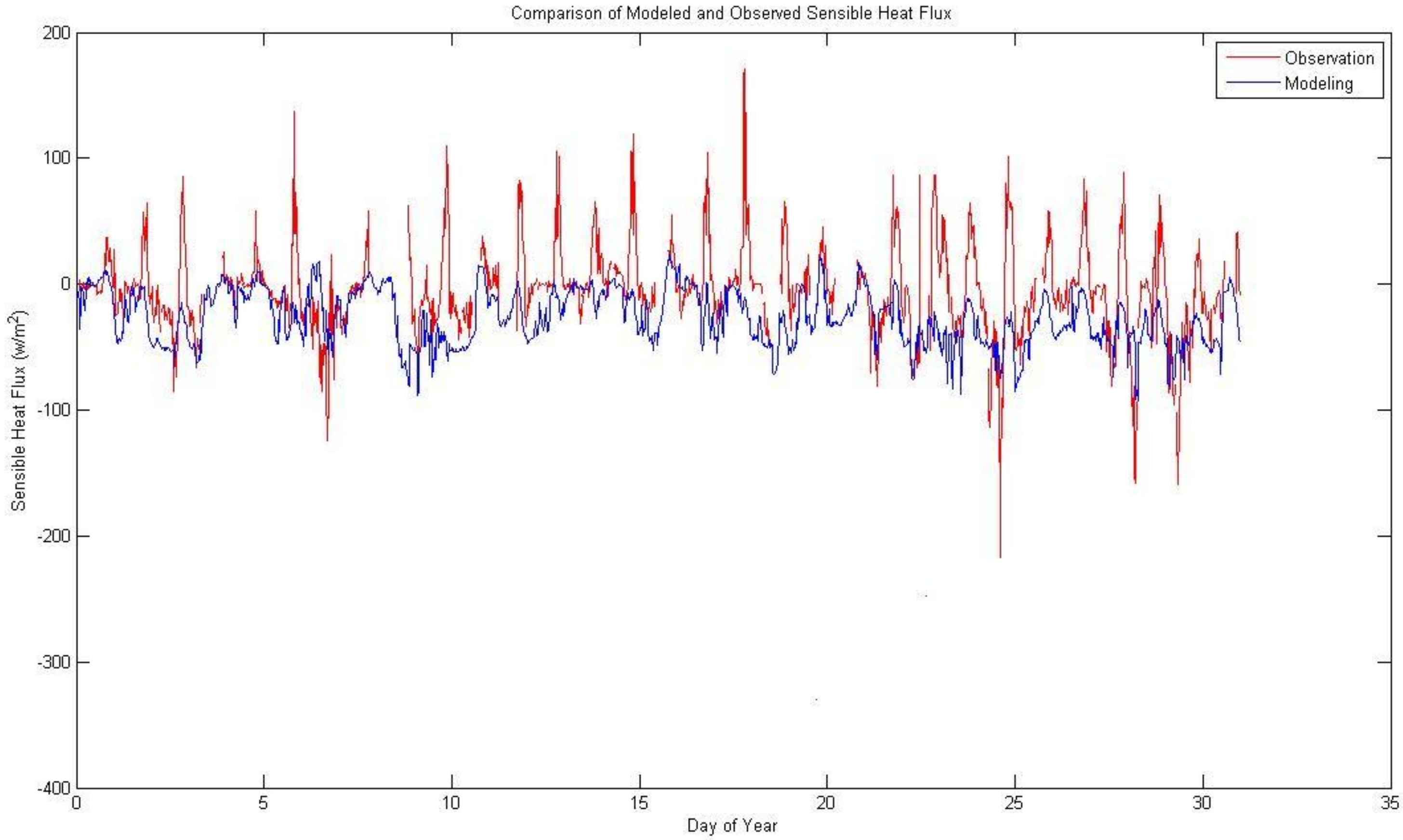
Results - Surface temperature

- Xie model



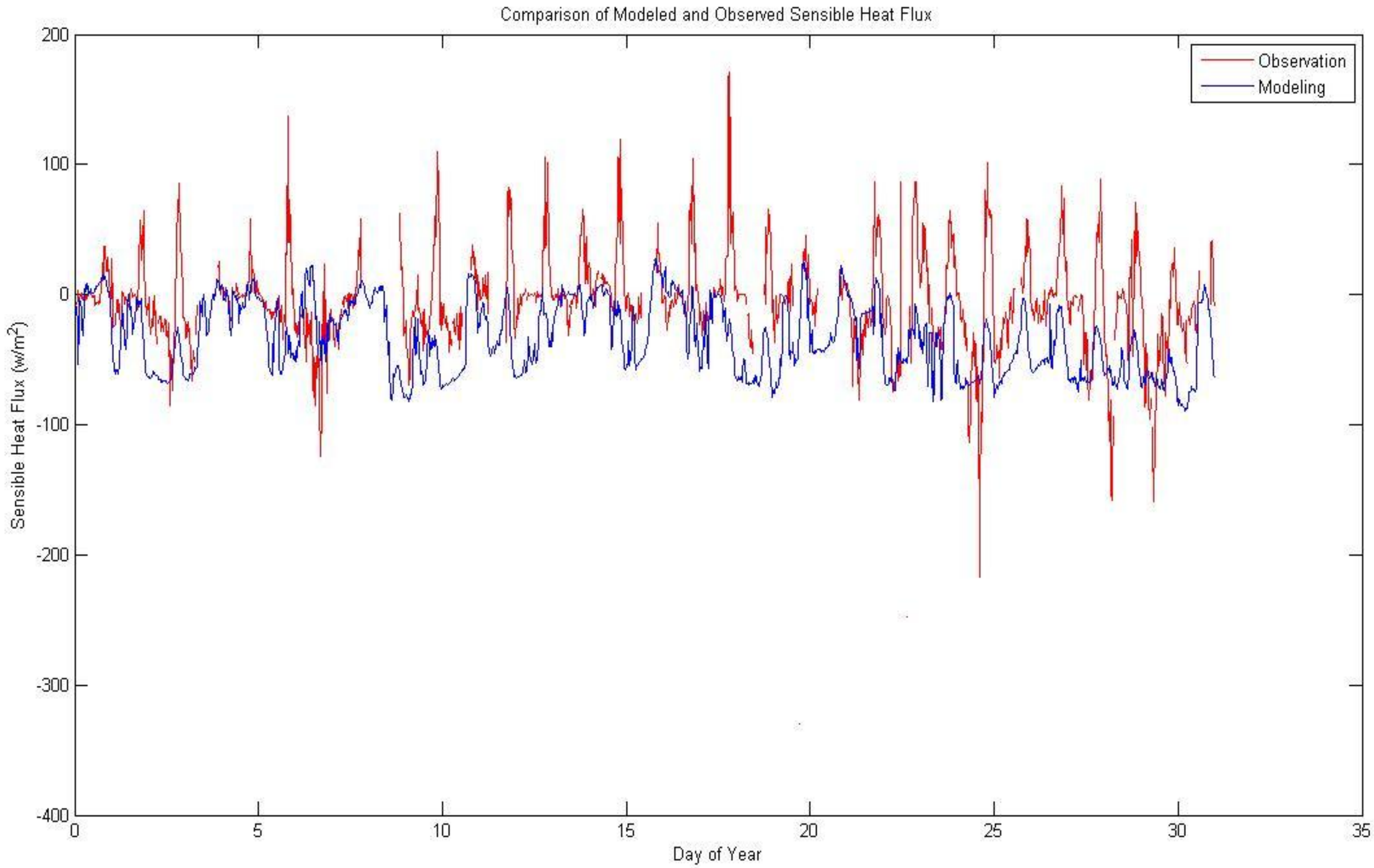
Results – sensible heat flux

- Thom model



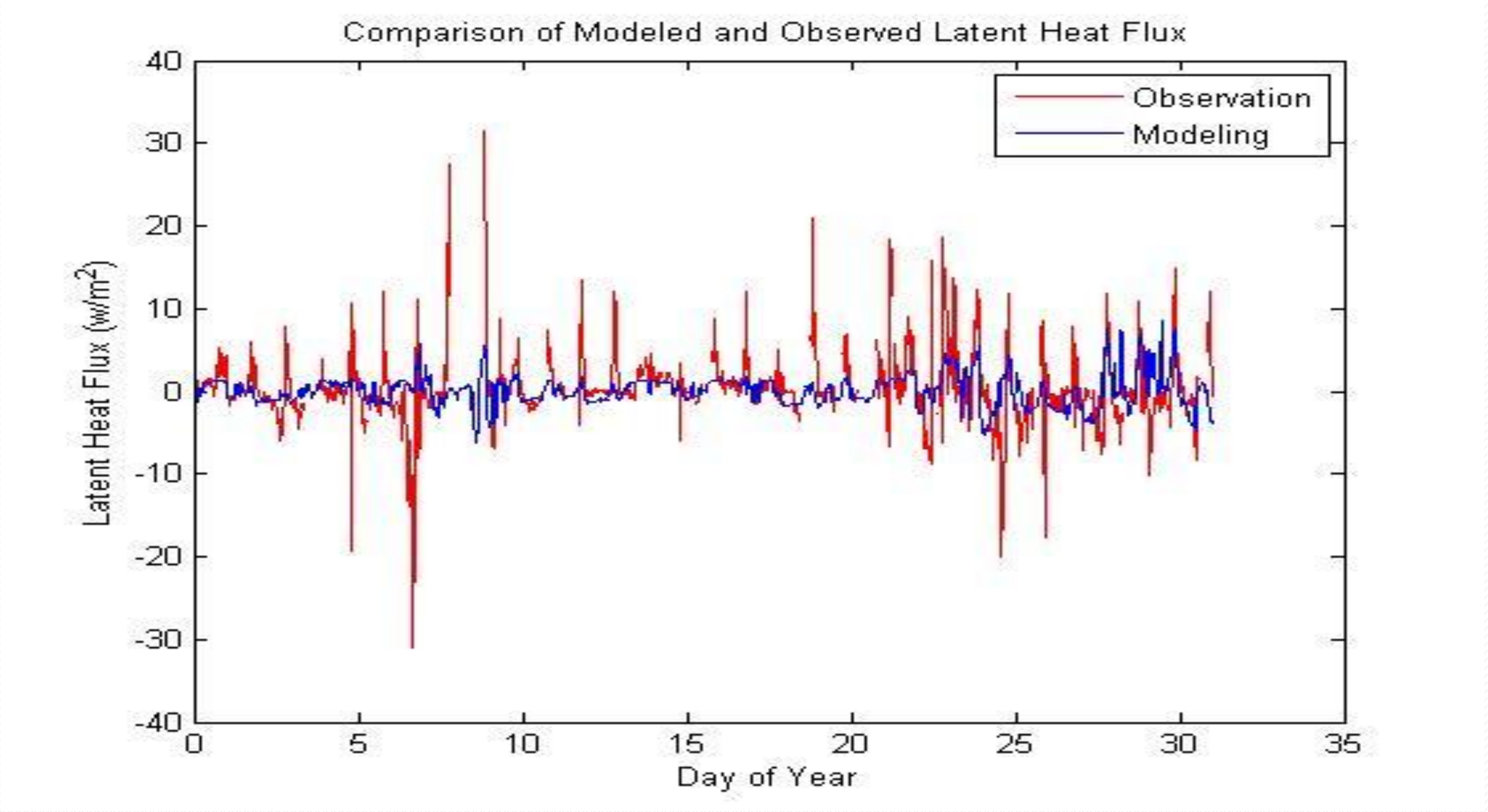
Results – sensible heat flux

- Xie model



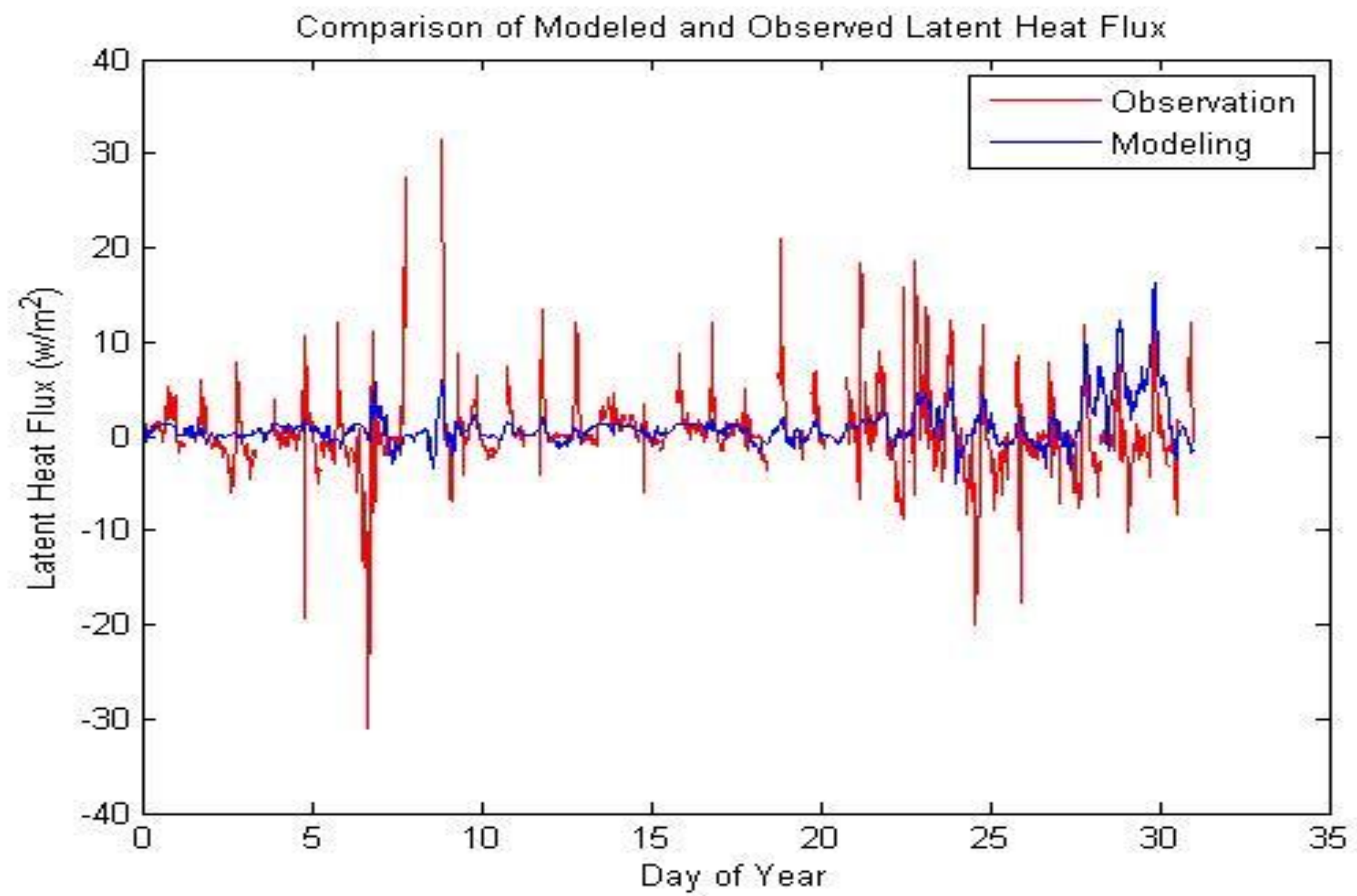
Results – latent heat flux

- Thom model



Results – latent heat flux

- Xie model

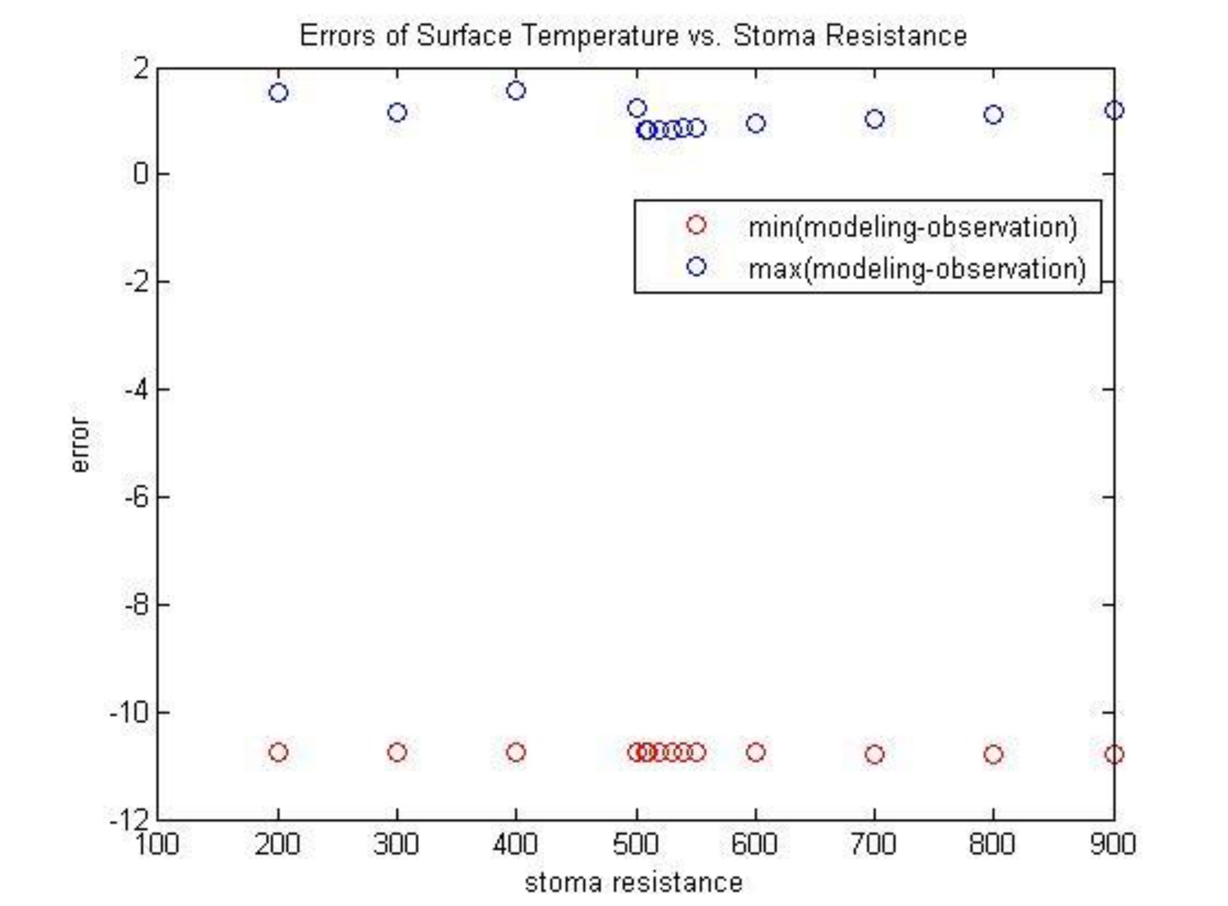


Discussion

- Why the heat flux modeling results are bad:
  - r_s is set as a constant
  - Soil heat flux G is not taken into account
  - Real temperature vs. Potential temperature
  - Reliability of the turbulent flux measurement
  - Need your ideas

Discussion

- *Tuning value of r_s by examining the error of Ts*



Discussion

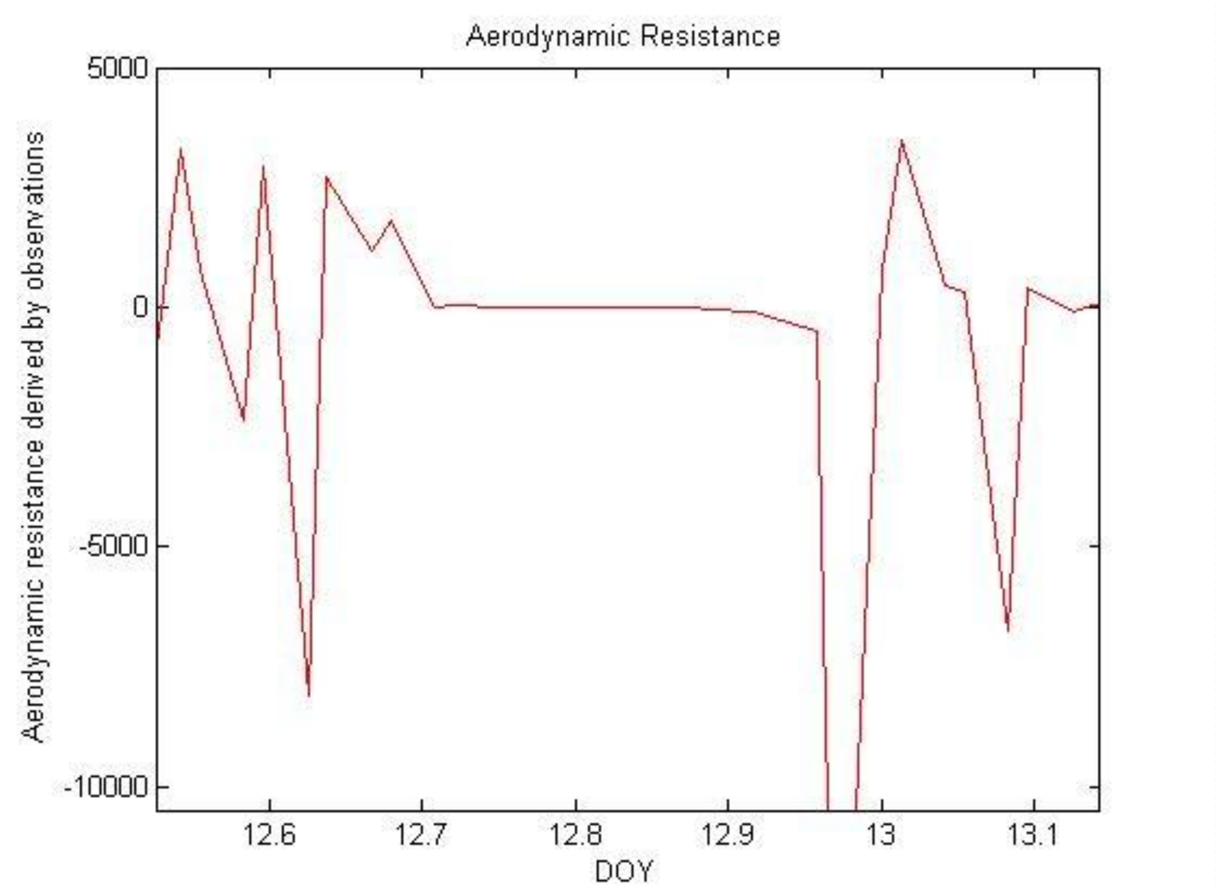
- Diagnostic form
  - *heat capacity of the canopy is assumed as zero*
  - *Not take into account the canopy heat flux G*

Discussion

- Temperature
  - *using real temperature, rather than potential temperature, since only have the pressure measurement at one level*

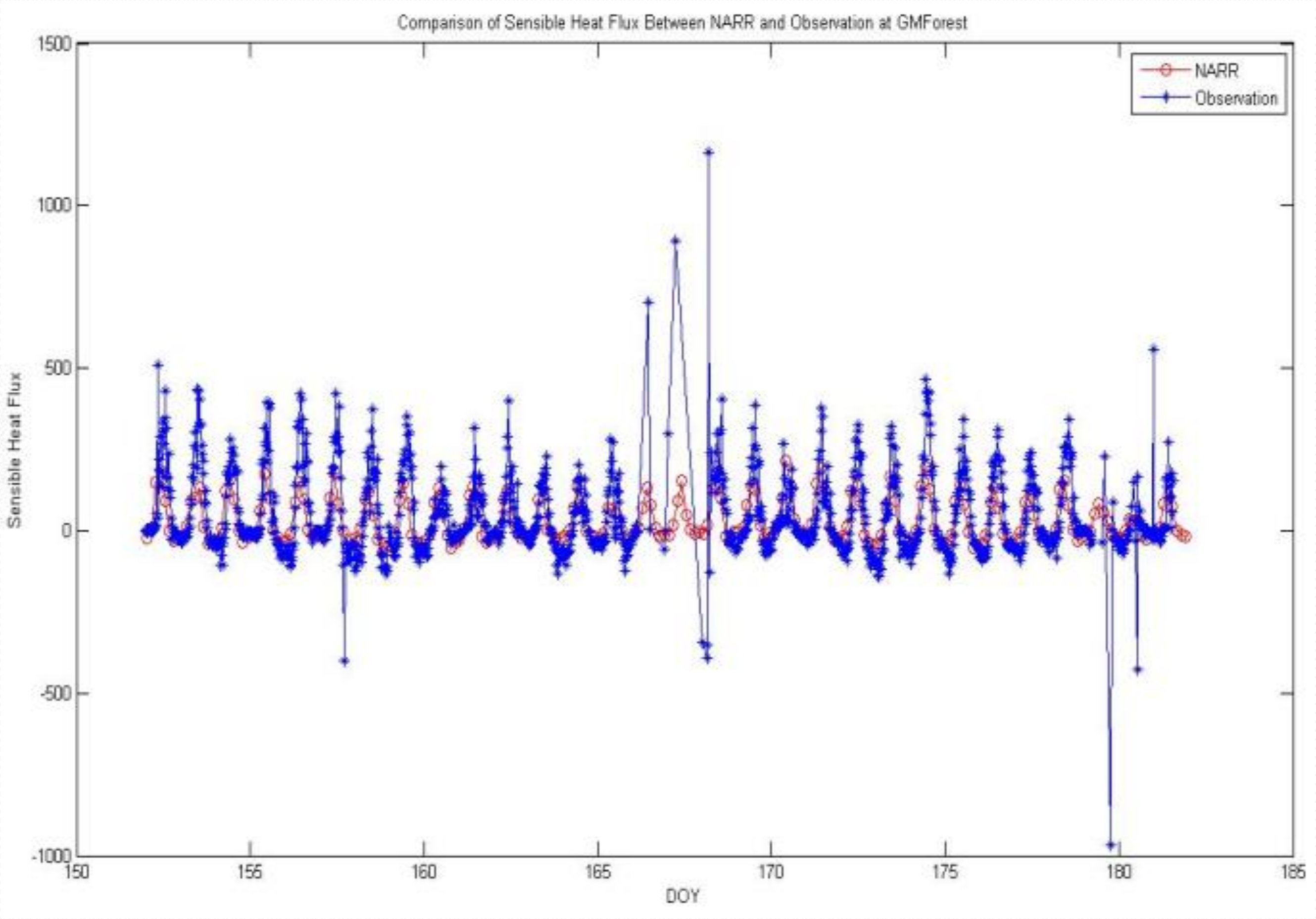
Discussion

- Reliability of the turbulent flux measurement



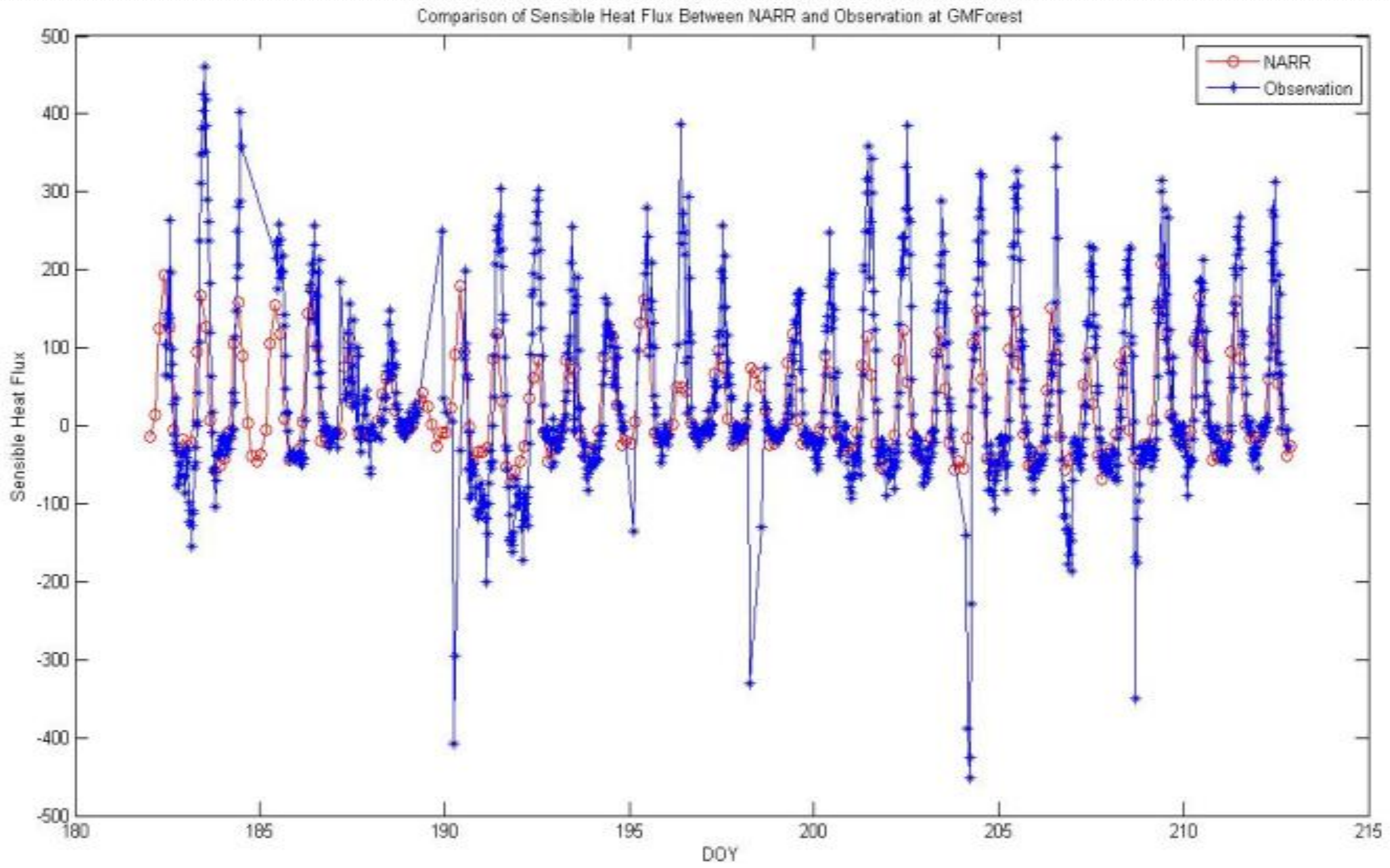
Discussion

- NARR prediction



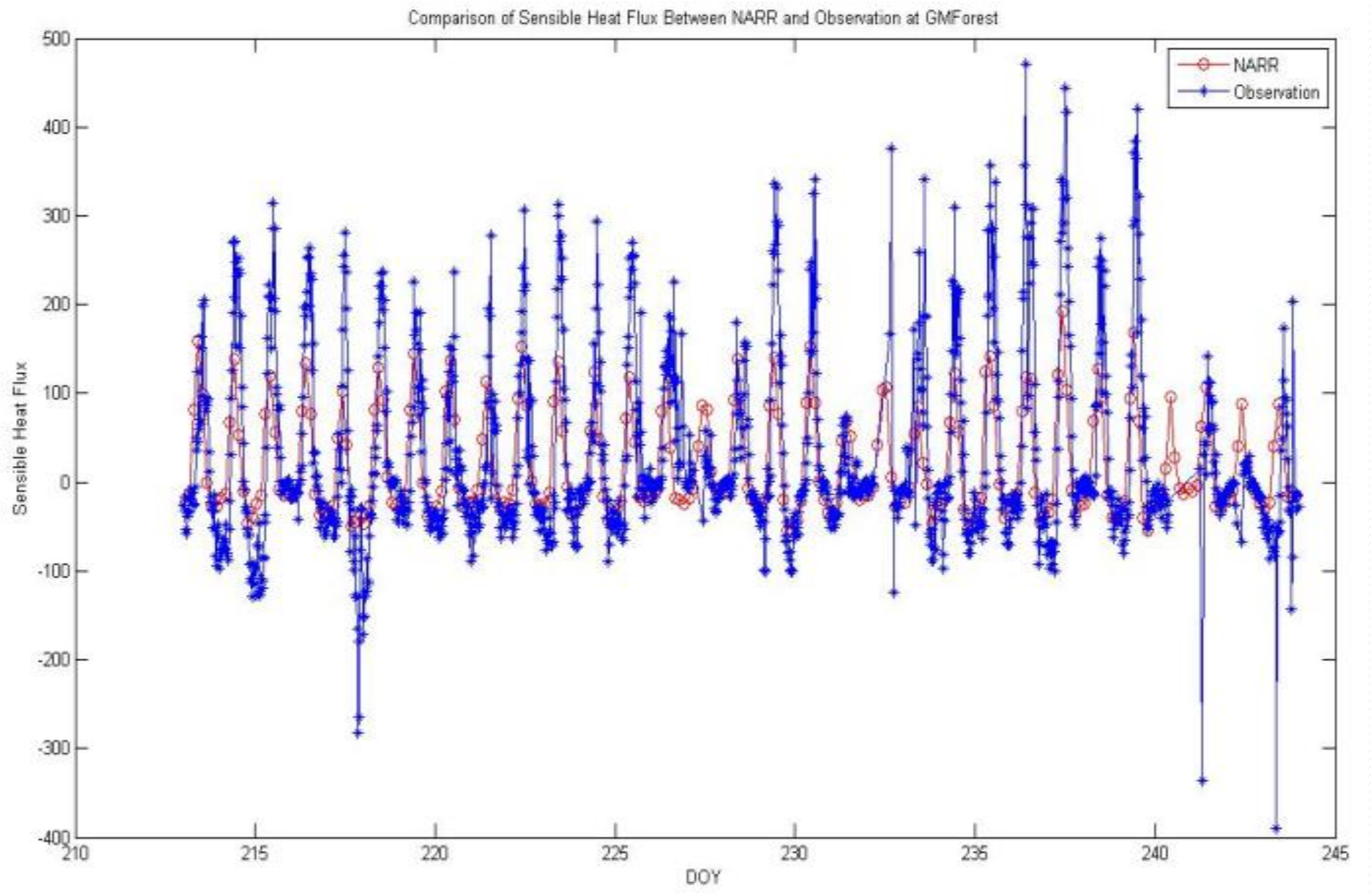
Discussion

- NARR prediction



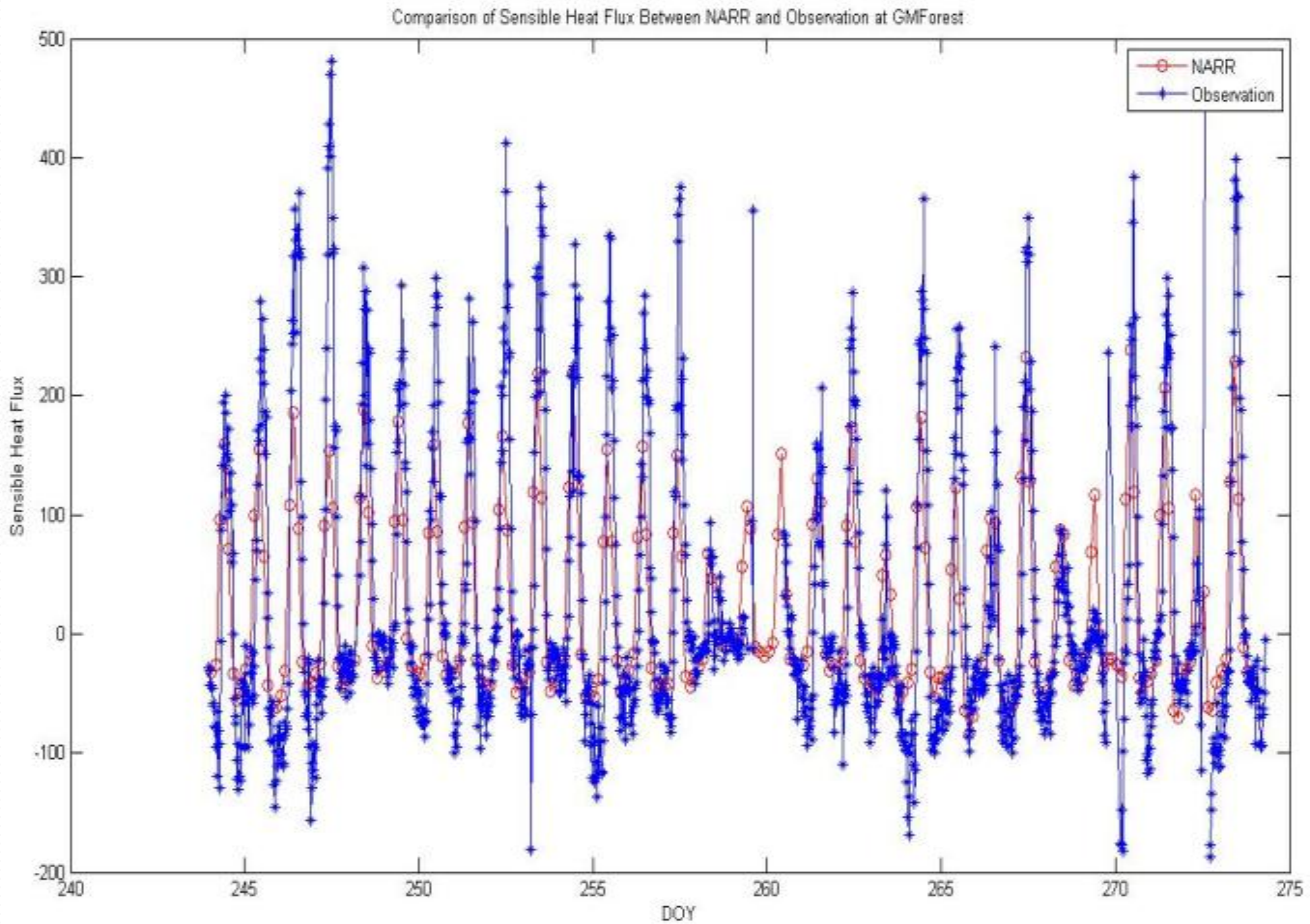
Discussion

- NARR prediction



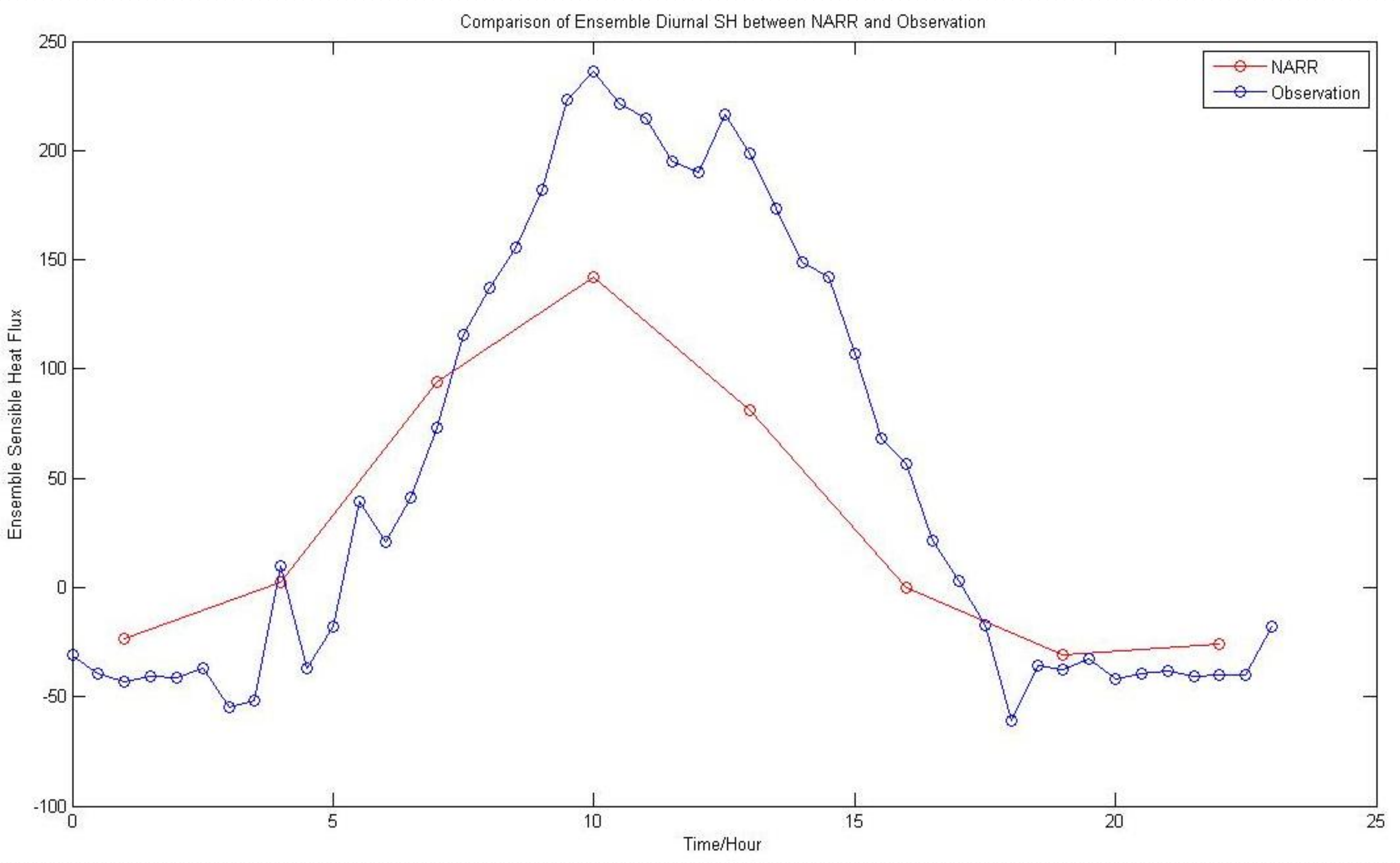
Discussion

- NARR prediction



Discussion

- NARR prediction



Thank you!

Comments and questions?

Updates: Albedo Correction 2010-06-09

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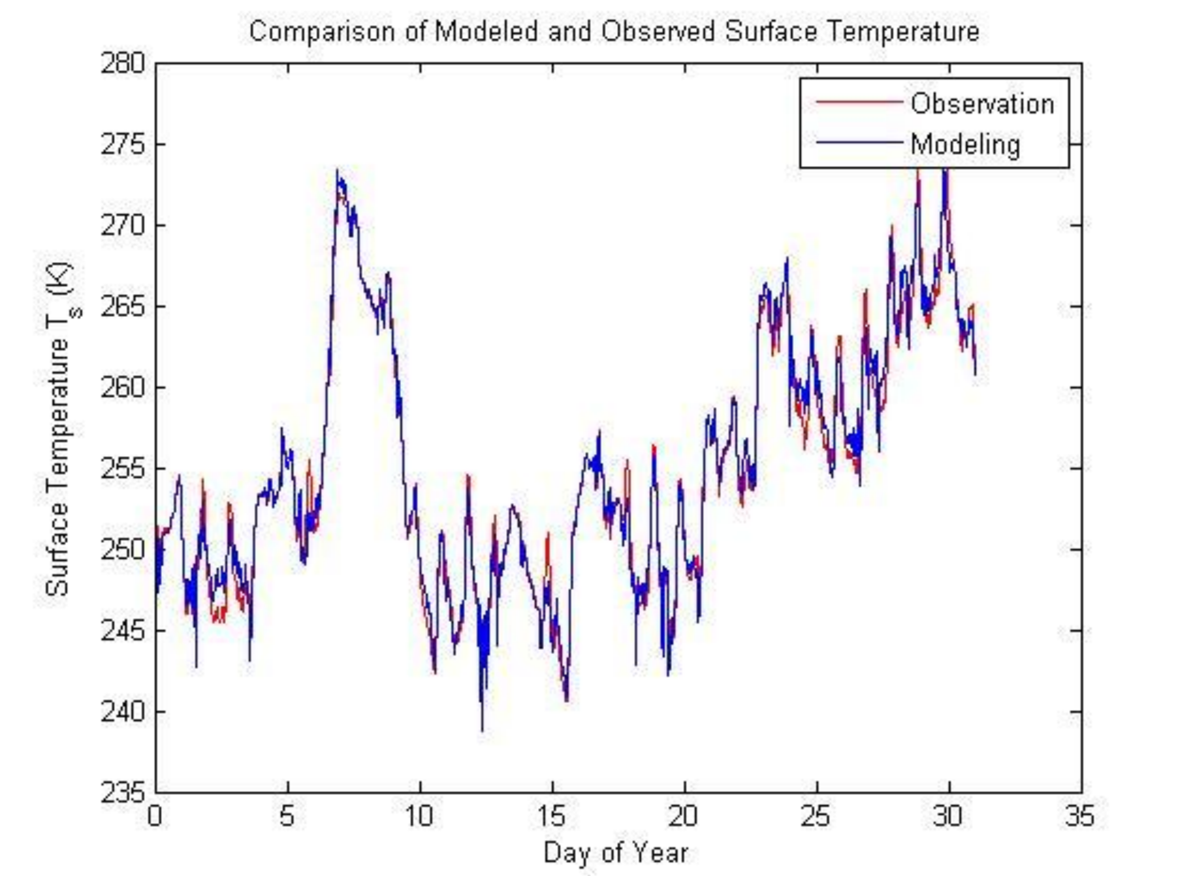
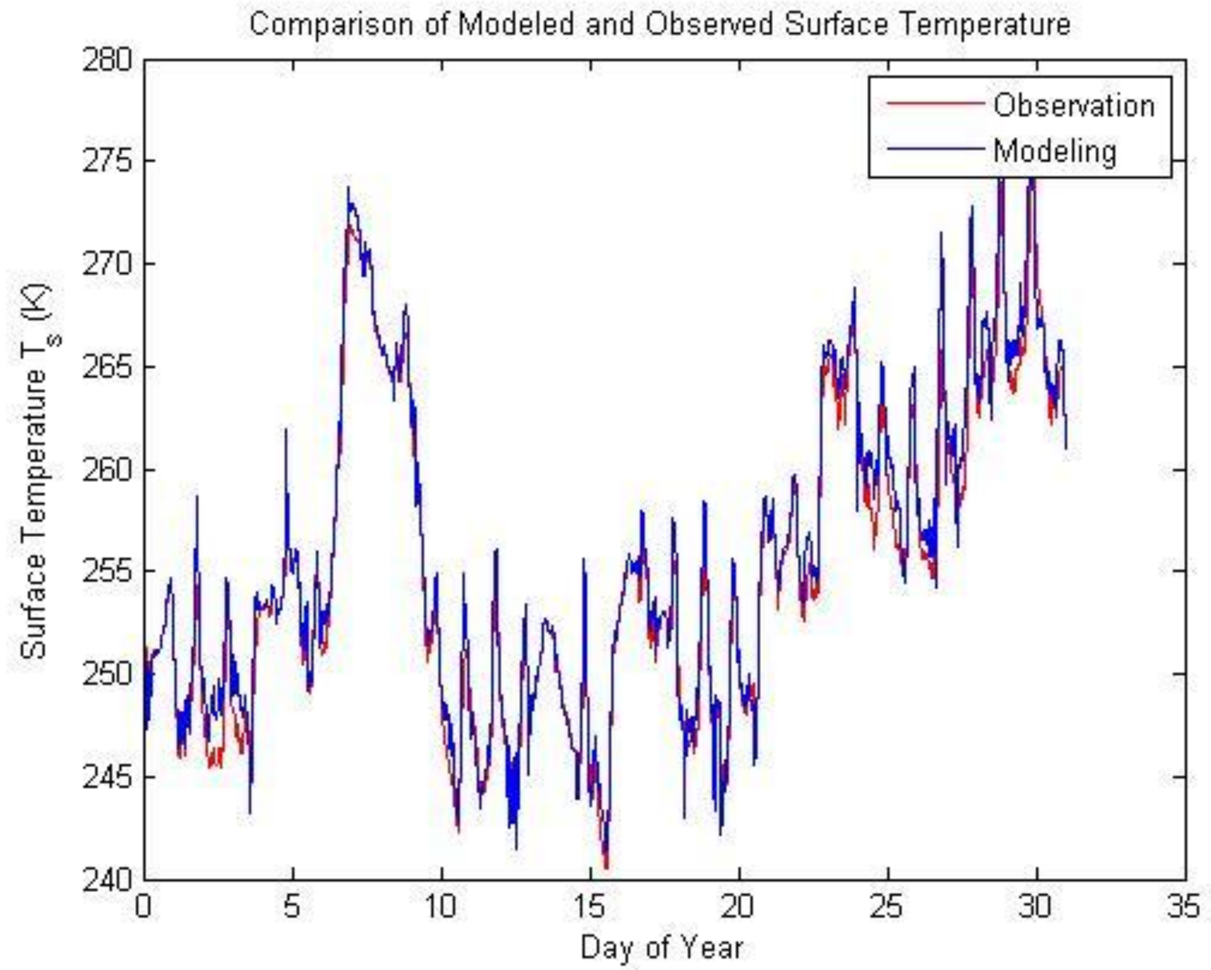
Results - Surface temperature

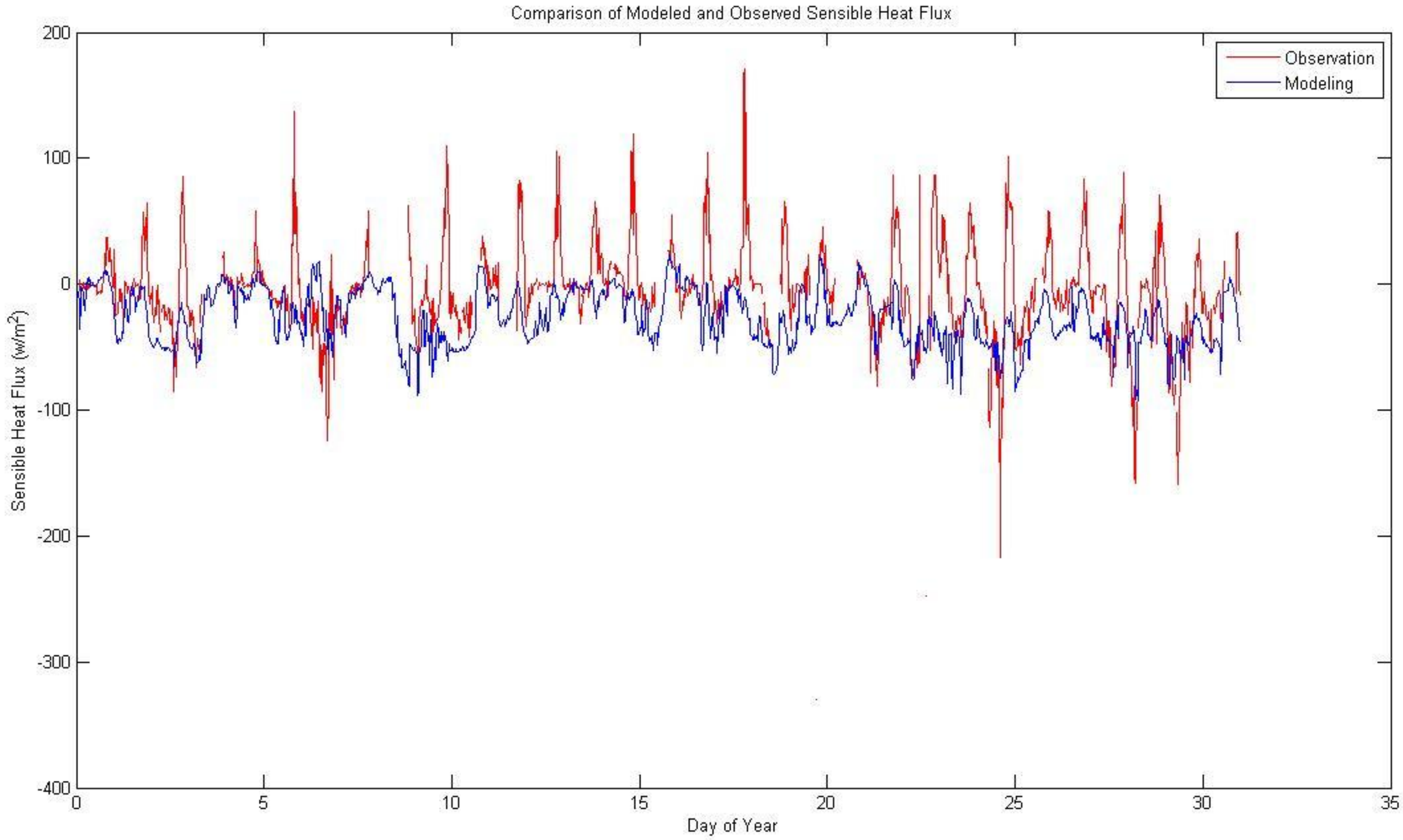


Results - Surface temperature



Results – sensible heat flux

- Thom model



Results – sensible heat flux

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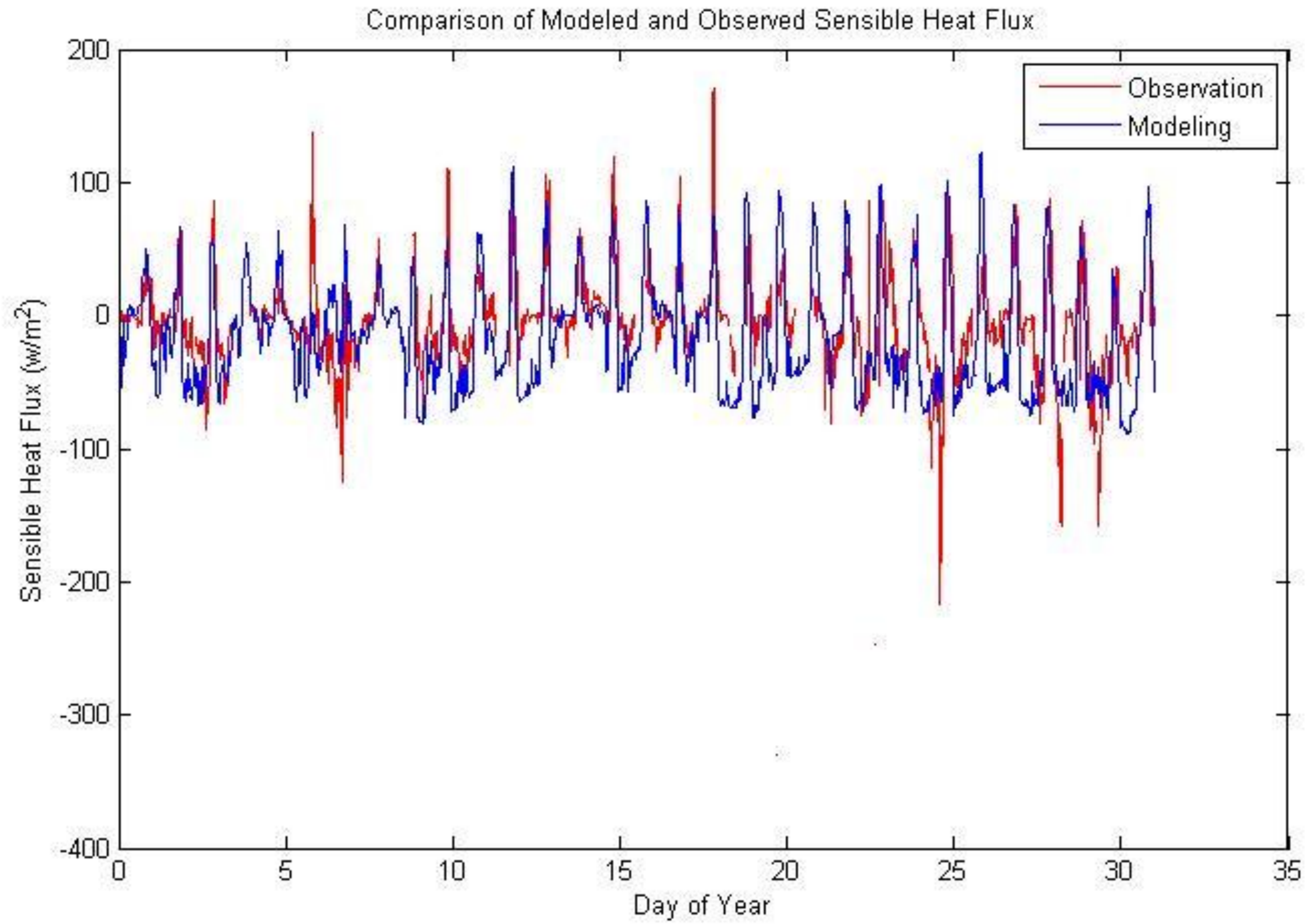
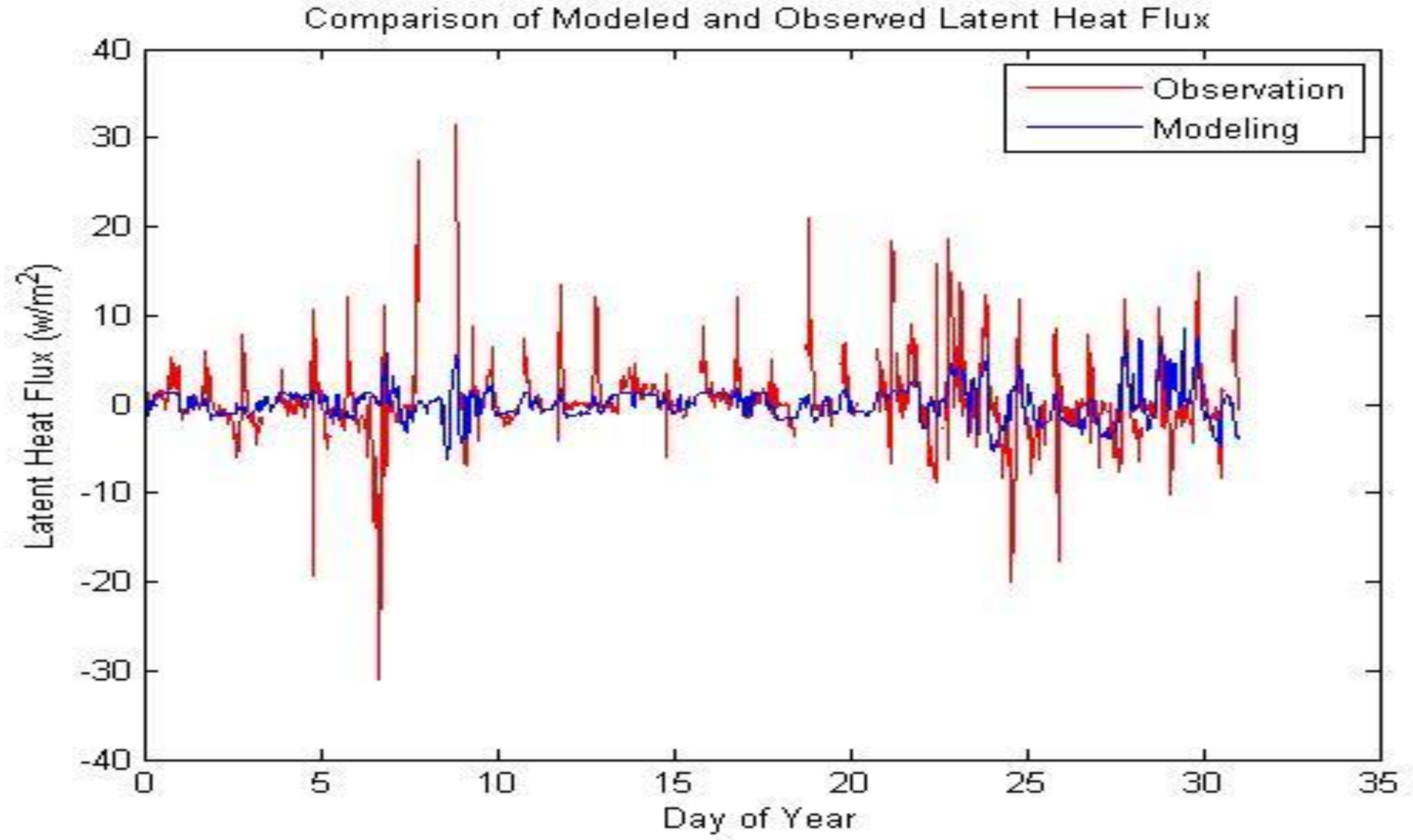
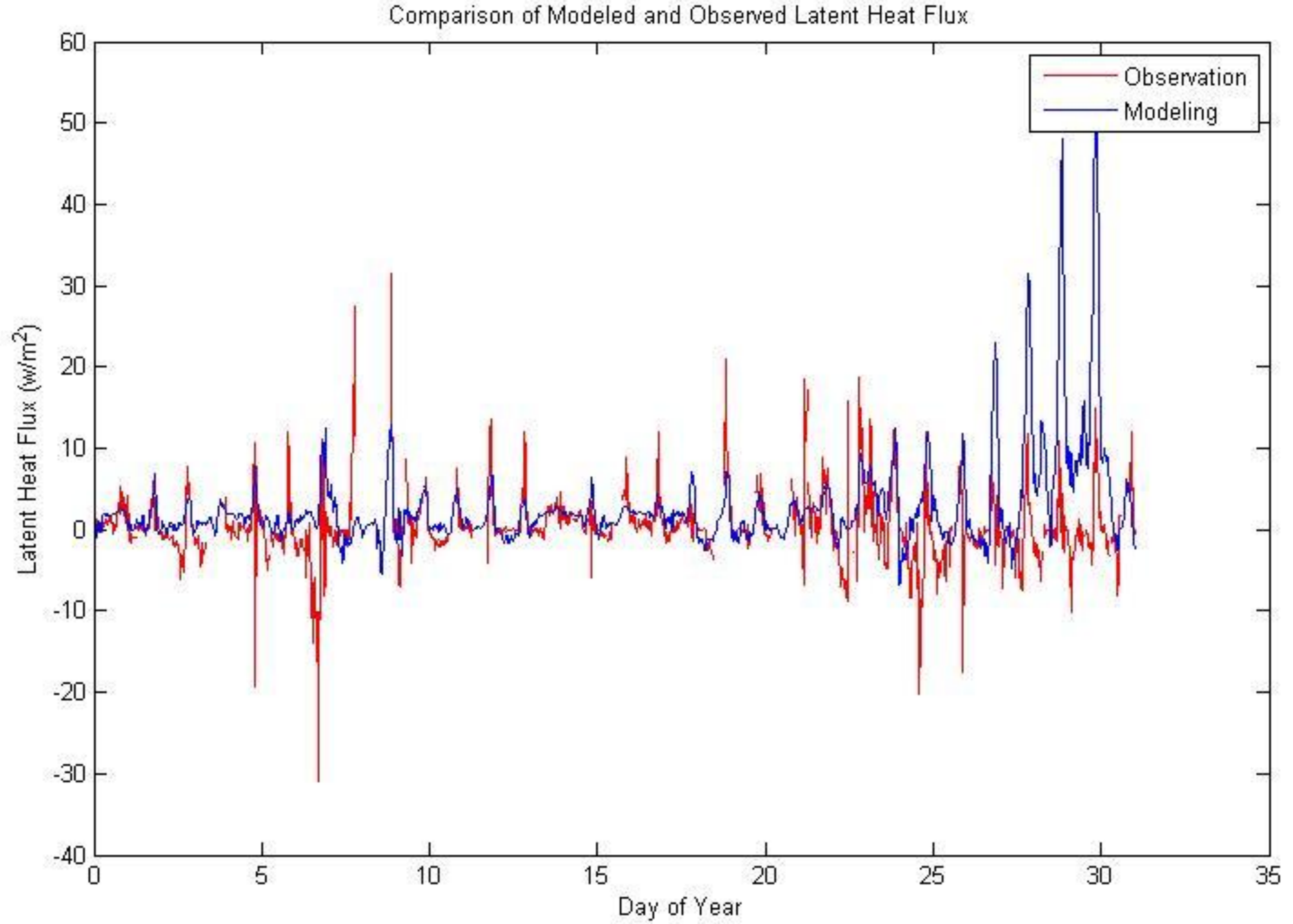


Results – latent heat flux

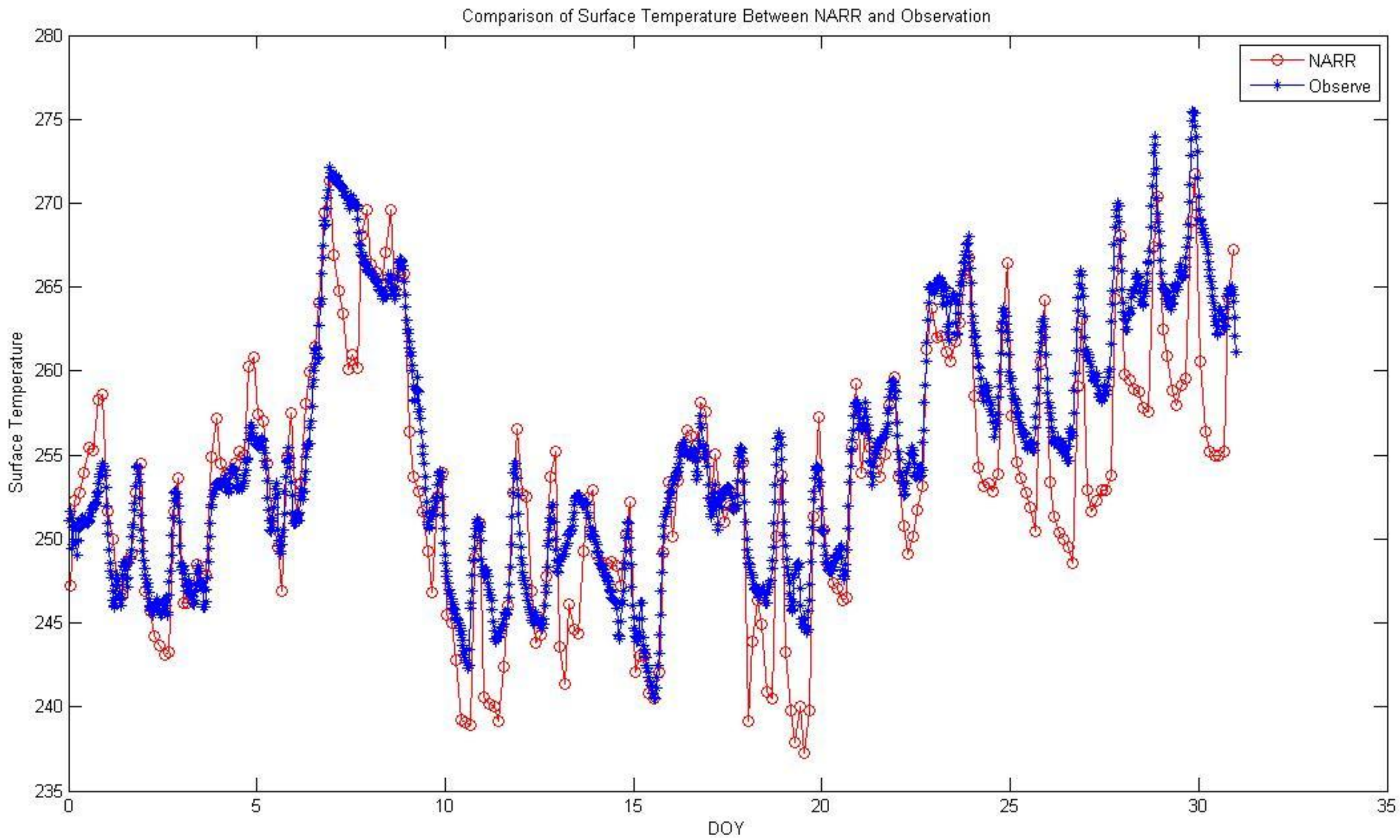
- Thom model



Results – latent heat flux



Observation Check with NARR



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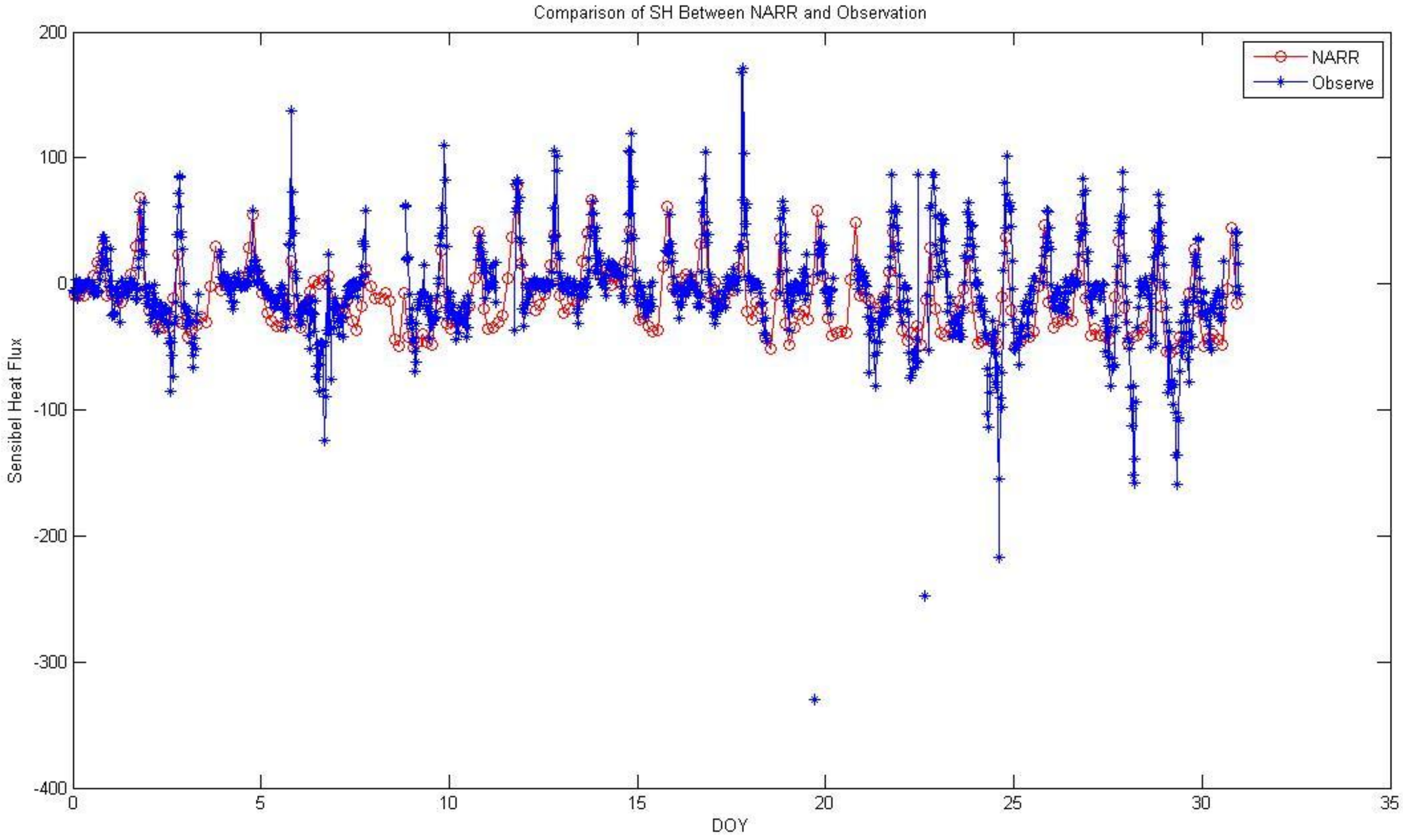
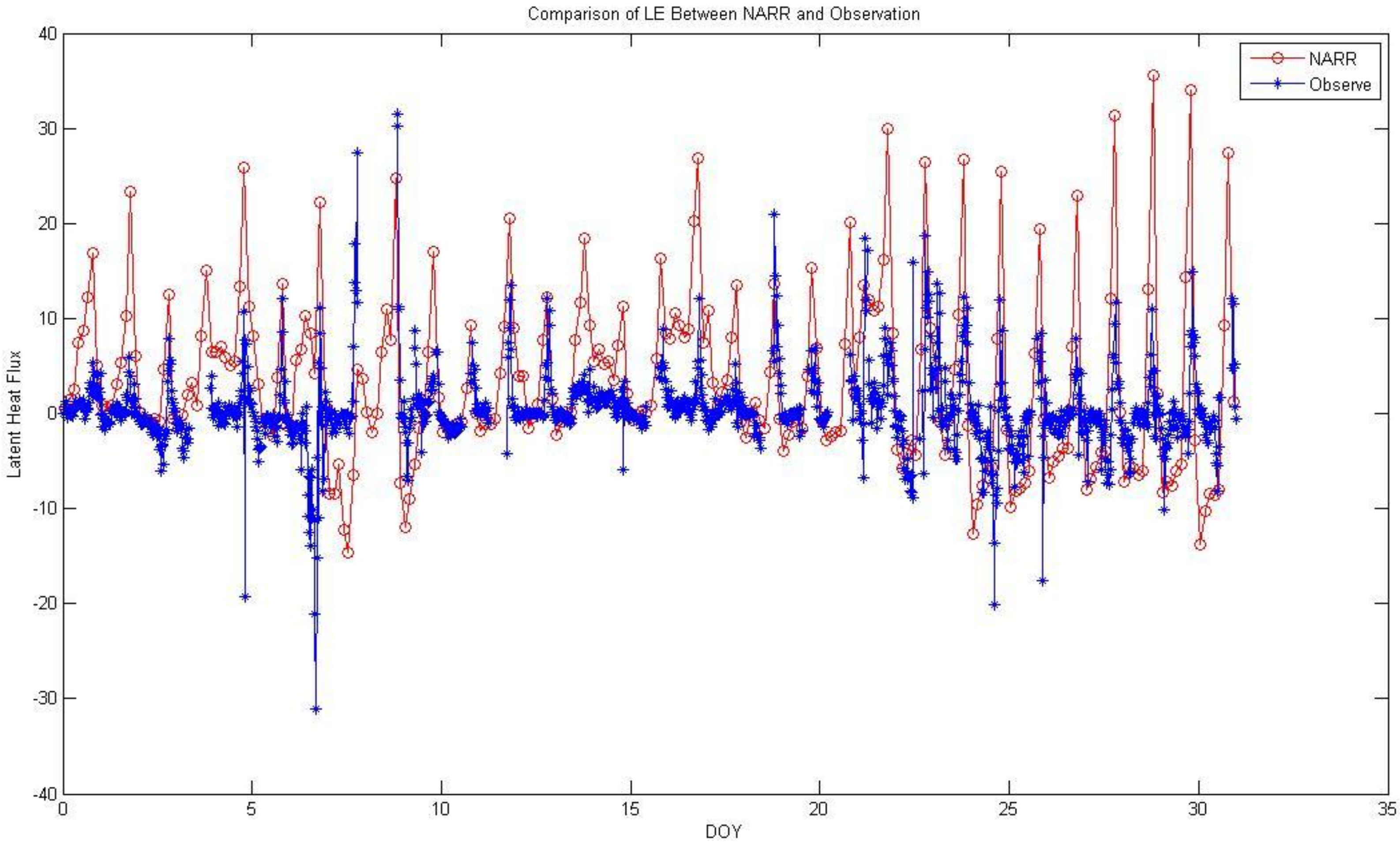


Observation Check with NARR



Subroutine for Canopy Resistance

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Canopy Resistance

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 102, NO. D24, PAGES 28,915–28,927, DECEMBER 26, 1997

Energy balance and canopy conductance of a boreal aspen forest: Partitioning overstory and understory components

P. D. Blanken,[1] T. A. Black,[1] P. C. Yang,[1] H. H. Neumann,[2] Z. Nesic,[1]
R. Staebler,[2] G. den Hartog,[2] M. D. Novak,[1] and X. Lee[3]

Abstract. The energy balance components were measured throughout most of 1994 in and above a southern boreal aspen (*Populus tremuloides* Michx.) forest (53.629°N 106.200°W) with a hazelnut (*Corylus cornuta* Marsh.) understory as part of the Boreal Ecosystem-Atmosphere Study. The turbulent fluxes were measured at both levels using the eddy-covariance technique. After rejection of suspect data due to instationarity or inhomogeneity, occasional erratic behavior in turbulent fluxes and lack of energy balance closure led to a recalculation of the fluxes of sensible and latent heat using their ratio and the available energy. The seasonal development in leaf area was reflected in a strong seasonal pattern of the energy balance. Leaf growth began during the third week of May with a maximum forest leaf area index of 5.6 $m^2\ m^{-2}$ reached by mid-July. During the full-leaf period, aspen and hazelnut accounted for approximately 40 and 60% of the forest leaf area, respectively. Sensible heat was the dominant consumer of forest net radiation during the preleaf period, while latent heat accounted for the majority of forest net radiation during the leafed period. Hazelnut transpiration accounted for 25% of the forest transpiration during the summer months. During the full-leaf period (June 1 to September 7) daytime dry-canopy mean aspen and hazelnut canopy conductances were 330 mmol $m^{-2}\ s^{-1}$ (8.4 mm s^{-1}) (70% of the total forest conductance) and 113 mmol $m^{-2}\ s^{-1}$ (2.9 mm s^{-1}) (24% of the total forest conductance), respectively. Maximum aspen and

Canopy Resistance

- Canopy resistance shows a strong response to PAR, LAI, saturation deficit, air temperature and soil water content.
- The paper discussed the diurnal dynamic response to PAR and saturation deficit
- Also seasonal dynamics of canopy resistance, mainly dependent on forest LAI

Canopy Resistance

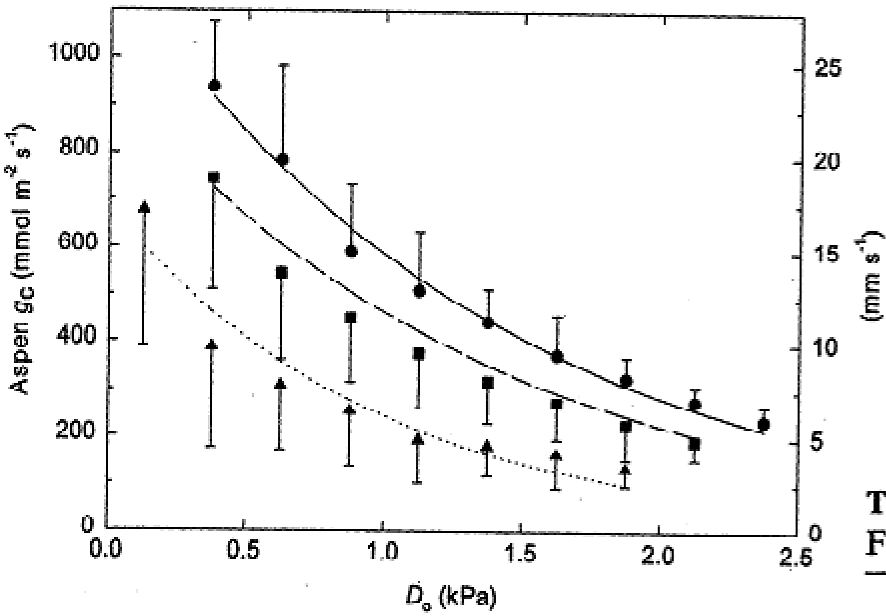


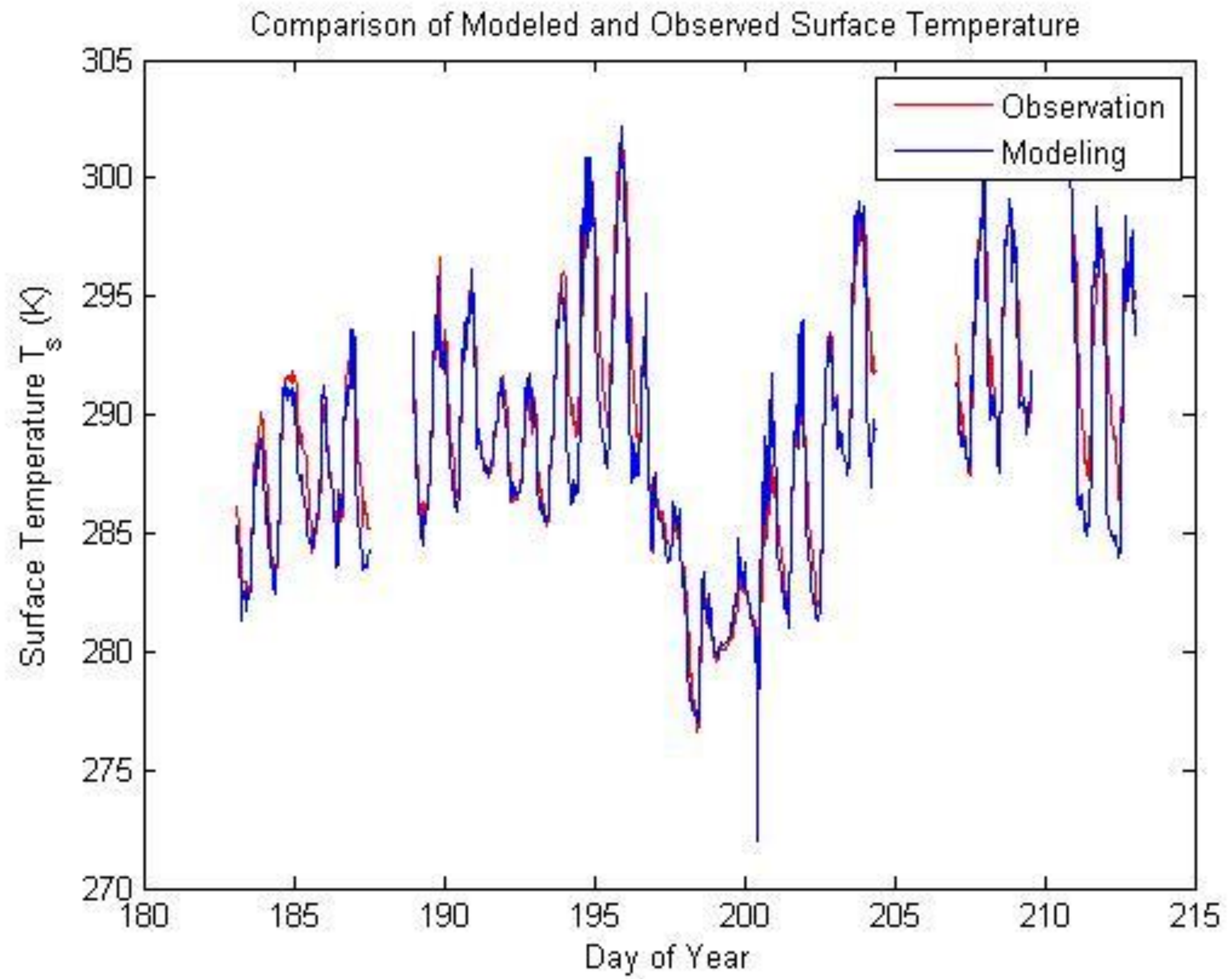
Table 2. Statistics Describing Nonlinear Curve Fits of the Form $g_c = g_{max} e^{-kD}$ As Shown in Figures 9 and 10

Q Interval, μmol m^{-2} s^{-1}	g_{max}, mmol m^{-2} s^{-1}	k	r^2	n
	Aspen			
$Q \geq 1400$	1203	0.72	0.99	247
$800 < Q < 1400$	950	0.80	0.95	735
$200 \leq Q \leq 800$	681	1.03	0.92	685
	Hazelnut			
$Q \geq 1400$	911	1.96	0.92	236
$800 < Q < 1400$	765	2.00	0.93	756
$200 \leq Q \leq 800$	398	2.54	0.87	648

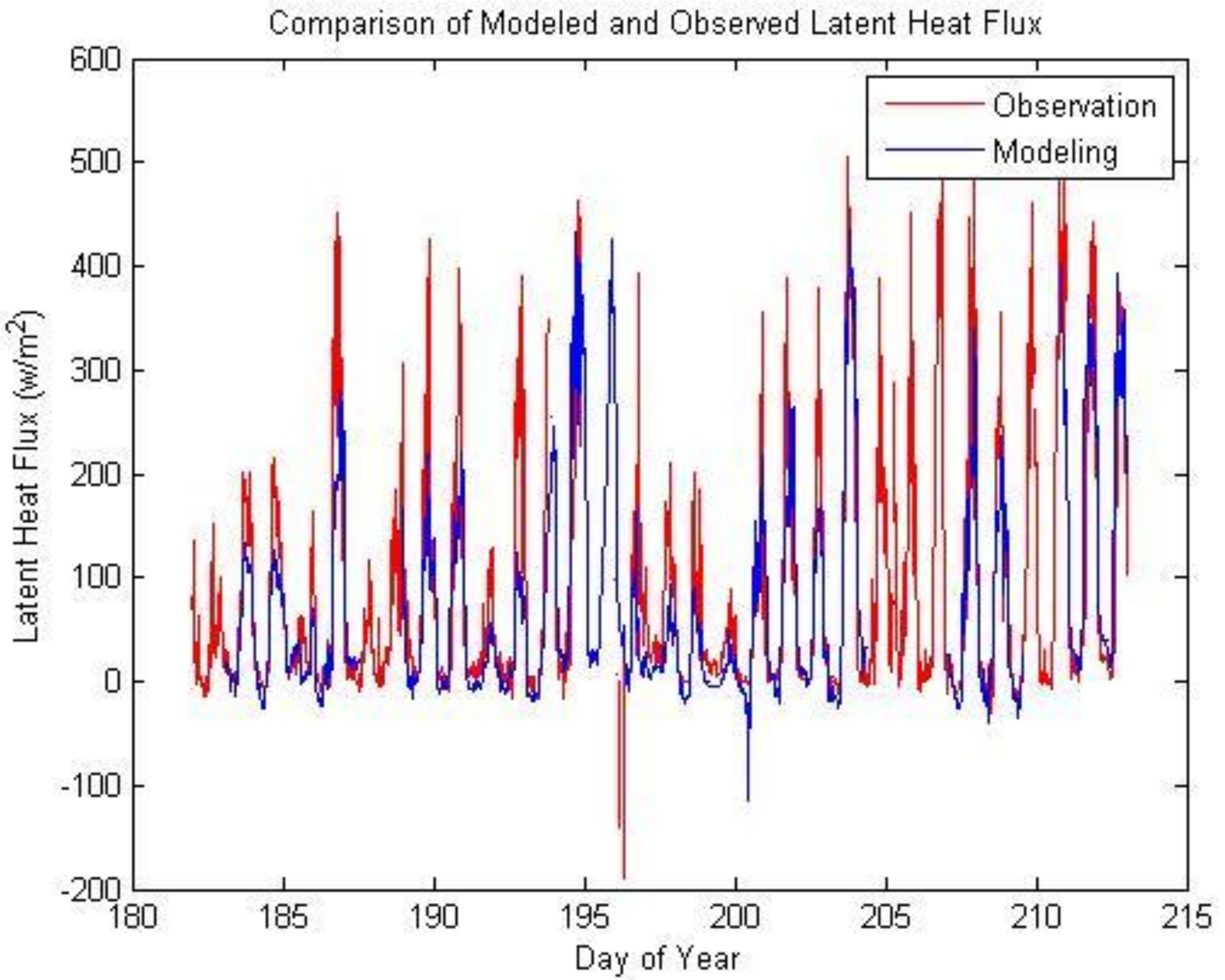
Canopy Resistance

- Simple method in the subroutine:
  - Parameterize it as a function of PAR and saturation deficit
  - Different PAR corresponds to different g_max
  - Exponentially decay on increasing saturation deficit

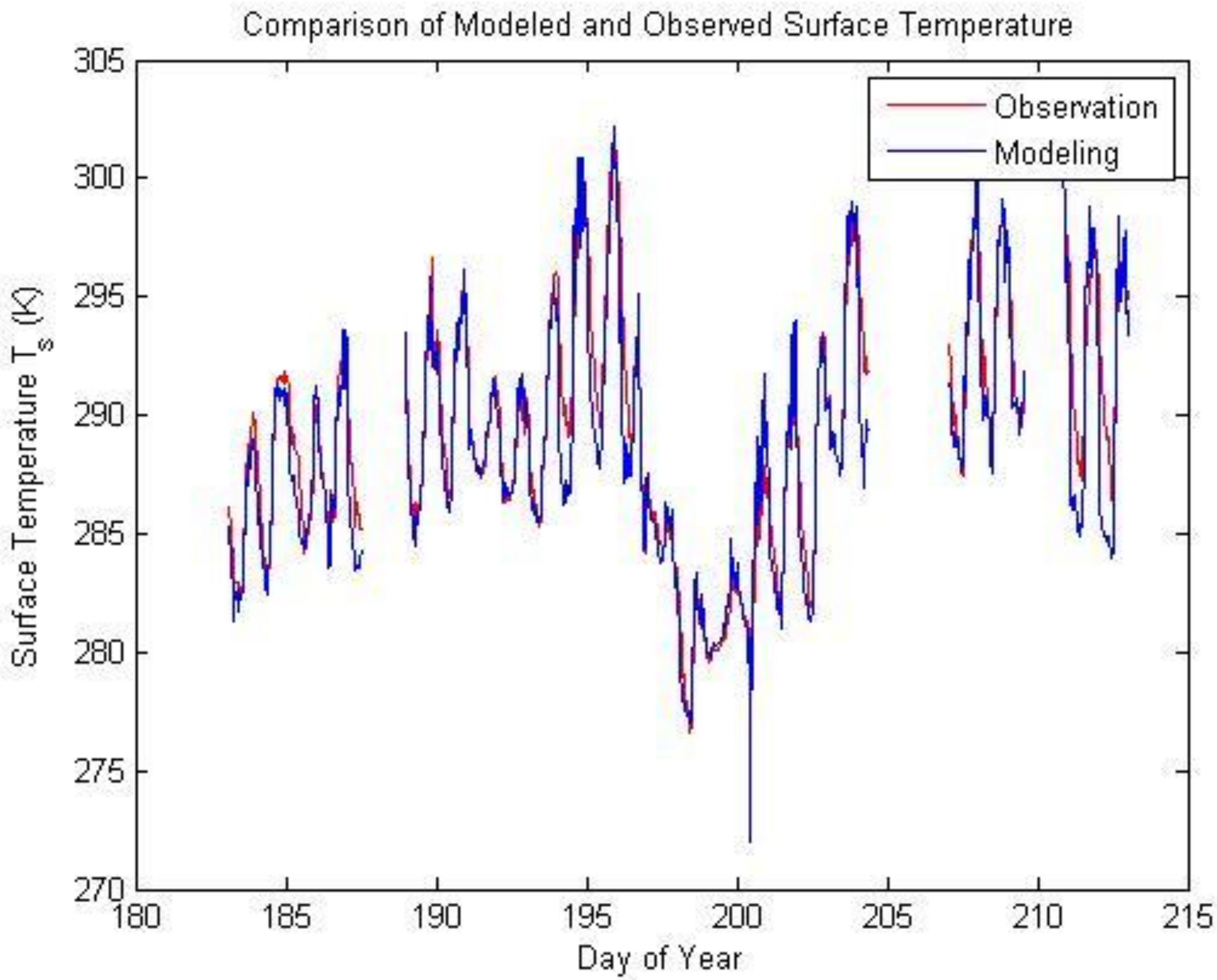
Canopy Resistance



Canopy Resistance



Canopy Resistance



Canopy Resistance